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Certain physiological factors involved in the curing and storage of hay

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CERTAIN PHYSIOLOGICAL FACTORS INVOLVED IN THE CURING AND STORAGE OF HAY

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TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

TABLE OF CONTENTS (Cont'd)

INTRODUCTION

Seventy-five million acres of land are devoted to hay production in the United States annually. Corn is the only crop that occupies a larger acreage, and corn and cotton are the only crops which exceed hay in total value. The hay crop is one of the three leading crops in each of forty-three States, and ranks fourth in the other five. The great value of the hay crop and its general distribution would seem to justify its receiving the careful attention of investigators. However, the investigational work with this crop has been largely confined to the manner and rates of seeding and to the securing of strains and varieties of plants suitable for hay purposes. The problem of curing and storing the crop has received very little attention.

Most hay is cured by the rule-of-thumb method. There is a rule telling when to cut, when to windrow, and when the hay is ready for the mow, stack or baler. These rules permit a wide latitude in their observance. The quality of the hay, however, suffers materially if the hay either is not ready or is past the proper stage when placed in storage. The effect of such a system has been to make the curing of hay a hap-hazard process largely dependent upon the weather. Many of the harmful effects of such a system of handling this important crop are largely hidden. The loss resulting from over-curing of hay has been shown to amount to twenty per cent in the feeding value (18). The losses resulting from under-curing, also, are tremendous. These losses express themselves in hot, heating and moldy hay, with occasional outbreaks of fire. Since most of these losses occur on the farm and are not reported it is impossible to even estimate their extent. The losses from this source which are known are those that interfere with the marketing of the hay or the extreme cases which result in the loss of the hay and barn by fire, started by so-called "Spontaneous combustion".

A loss of $30,000,000 annually in the United States is credited to fires resulting directly from improperly cured hay according to R. W. Dunlap, Assistant Secretary of Agriculture, (9, p. 4). The Fire Marshall of Ontario, Canada, states that "spontaneous combustion" of hay was the major cause of a $2,000,000 loss by fire in the one Province in 1927 (9, p.36). Likewise, the Fire Marshall of Iowa reports a loss of $102,292 in 1928 due to "spontaneous combustion" of hay (9, p.75).

To this loss by fire must be added the much greater loss in feeding value due to excessive heating in stacks and mows in which the heating did not proceed to the stage of actual ignition. A survey of Laupper (40) indicated that in Switzerland, for each 25 cases of fire caused by under-cured hay, there were 167 cases of carbonization resulting from the overheating of the hay. The hot, heating and moldy hay found at our terminal markets represents a serious loss. At the Kansas City Market, 1,220 cars, or 12 per cent of the hay offered on that market in 1927, was graded "U.S.Sample Grade" because of its hot, heating and moldy condition. In 1928, 3,373 cars or 17 per cent of those received, were graded as "U. S. Sample Grade" for the same reason. At the Chicago Market, 6 per cent of the cars received have been out of condition because of heating (9, p.70-73).

The literature available on methods of curing hay consists largely of popular articles in the Agricultural press. Most of these reports reiterate the rules of hay making without giving evidence to prove their value. Often, methods of handling the crop are advised which are decidedly questionable and contrary to known physiological principles. The general recognition of the many problems involved in hay curing is indicated by the great diversity of untested theories and ideas advised by people desirous, either of improving the quality and ease of handling the hay crop, or of selling some special hay handling machinery. Some of the phases of hay curing concerning which experimental evidence is needed are mentioned in the following paragraphs.

The moisture content of hay plants in the field has been considered an important factor in determining the best time of day to cut. Supposedly, hay plants contain a much lower amount of moisture in the afternoon and hence, if cut at that time, the curing process would be shortened.

The known physiological functionings of the leaf in the transpiration process of normal growing plants has been assumed to play an important role in the moisture loss from the plant after it is cut for hay. The assumed application of these physiological principles has led to the rather general acceptance of the idea that keeping the leaves alive by shading and protecting them from rapid drying hastens the curing of the hay, and to the recommendation of specific systems of curing hay in swath, windrow and cock.

Very little is known of the physical and chemical changes which take place in hay when stored. The process of salting hay is used and rather extensively advised, but with very little evidence of the value of salt as a preservative for hay. The knowledge of how the moisture content of hay when placed in the mow influences the degree of heating and the tendency to mold, or to produce the so-called "brown hay", has many practical applications, with but little experimental data available on the subject.

The introduction of machinery for mowing, loading, stacking or baling have made necessary a knowledge of the maximum moisture content at which hay can be safely stored. The problems involved in the proper curing of hay are becoming important with the more general use of large capacity machines. These machines, hay loaders. forks, slings, stackers and balers, tend to increase the danger from heating. The use of such machinery enables one man to heap great masses of hay in the mow or stack in a short time, thus interfering with the radiation of heat and of moisture which could readily take place if the hay were spread out more as it was stored.

The studies reported here were undertaken to obtain experimental evidence on which to base recommendations regarding the field curing and the storage of hay and are grouped under:

I. Experiments in the Field Curing of Hay, and

II. Experiments in the Storage of Hay.

Experiments in the field curing of hay include: methods of measuring the degree of curing; the relative rate of curing in swath, windrow and cock; the influence of methods of curing on the quality of the product; and a physiological study of the leaf in relation to moisture loss during the curing process.

Experiments in the storage of hay include: the effect on the quality of storing hay with varying moisture content; the influence of the moisture content on the degree of heating; the determination of the quantity of carbon dioxide and of oxygen as these may indicate the degree of respiratory activity and possible chemical changes; and the effect of salt in varying quantities on heating, molding, and other conditions influencing the quality of the product.

I. EXPERIMENTS IN THE FIELD CURING OF HAY

Historical

Although the agricultural press contains many articles on hay curing and the experiment stations have issued many popular bulletins on the subject, very few experiments on methods of curing have been reported. At the time this study was begun, no research bulletin had been published on the subject, and in 1930 only a portion of one such research report is devoted to studies in the curing of hay. Practically all of the recommendations on methods of curing have been based on observations rather than actual measurements.

The literature on hay curing which tends to stress the general rules of procedure is rather extensive. Among the authorities to be noted are: McClure (46), (47), (48) and (49); Yerkes and McClure (85); Piper et al (63); Wallace (79); Vinall and McKee (77) and Rather (65). General discussions of hay curing methods have been included by the authors of most texts which deal with Forage Crops: Piper (61); Hunt (30); Shaw (70); Cox (18); Stewart (72); Coburn (13); and Hutcheson and Wolfe (31). A compilation of considerable experimental evidence was made by Hughes and Henson (29).

The general recommendations regarding the methods of curing legume hays vary somewhat with the section of the country for which they are made. The majority of the Eastern writers quote Brooks (6) on Clover Hay in New England and favor late afternoon cutting, handling the hay as little as possible afterwards, raking and, with good weather, cocking in the afternoon of the second day. If the weather is not favorable the hay is left in the windrow over night and cocked on the afternoon of the third day.

Very frequent reference to afternoon cutting is found with the suggestion that the hay is partially cured at this time and can therefore be expected to cure out more rapidly than if cut in the morning.

The necessity of using care in the handling of leguminous hay has been emphasized repeatedly and experimental evidence has shown serious loss from careless methods. Headden (24) found that the crude-fiber was increased 12.37 per cent, the protein content decreased 7.70 per cent and the nitrogen-free extract decreased 5.07 per cent, when hay was exposed to 1.76 inches of rain during a 14-day curing period. Cooke (15) found a loss of from 5.1 to 26.1 per cent in dry matter under ordinary methods of curing as an average of 8 tests with varying weather conditions.

Shuey (71) reports a loss of dry matter in field cured alfalfa of 12.0 per cent when no rain fell on the hay, and a loss of 22.8 per cent when exposed to rain. He reports the loss of leaves as 5.6 per cent, with no rain while the hay was curing, and a loss of 17.6 per cent when rain fell during the curing of the hay.

Willard (83) states that the loss by weathering during the field curing of alfalfa in Kansas is due to fermentation processes, mechanical losses, and the dissolving out and removal of substances. Alfalfa exposed to three showers, during which 1.76 inches of rain fell, lost 60 per cent of its protein, one-third of its fats, 41 per cent of its nitrogen free extract, and 28.7 per cent of its ash. The percentage of fiber increased.

Kenney (35) found a loss in leaves varying from 6 to 48 per cent, with an average loss of 12.43 per cent, in 41 lots of alfalfa in Kansas. Salmon, Swanson and McCampbell (68) found that as an average of four maturity stages, 19.0 per cent of the leaves, (9.2 per cent of the dry matter) was lost in harvesting.

The only experimental comparison in which the loss of dry matter was measured for different methods of curing the hay is that of Kiesselbach and Anderson (36, p.111). They found 90.7 per cent of the dry matter recovered in swath cured hay; 94.5 to 99.9 per cent in windrowed hay, and 95.0 to 96.3 per cent when the hay was cured in the cock.

The idea of maintaining the leaf in a living condition, for as long a period as possible, is advocated quite generally in the popular literature on the subject of methods of curing hay. The usual method advised for maintaining the leaf in a living, functioning condition has been to windrow the hay immediately after cutting. The claim is often made that this slow curing at first actually hastens the complete curing, because the more rapid withdrawal of moisture from the stems soon over-balances the rapid loss of moisture from the leaf which occurs in swath curing.

Wallace (79) was one of the first to stress the value of keeping the leaves alive for rapid withdrawal of moisture from the stems in curing clover hay. Other writers placing emphasis on this point are: Rather(65), (66); Cox (17), (18); Wing (84); Pieters (60); Waldron (78); McClure (49); Roberts and Kinney (67); Mohler (55); Carrier (12); and Stewart (72). Many others mention this idea as important.

Adams (1) in connection with the "Dain System" of making hay has been an earnest advocate of the idea. In practice, however, his method of curing hay does not involve such an immediate windrowing as to lose all of the benefits of the rapid drying that occurs in the first one or two hours in the swath. The value of early windrowing in producing a good quality hay, and in preserving the leaves on the plant, has been generally accepted but the truth of the theory that the living leaf functions in the withdrawal of water from the stem during the curing process has been questioned.

Piper et al (63) state that there is serious doubt whether or not the leaves of cut plants continue to function as "pumps" to draw water from the stems of the plants. Vinall and McKee (77) give the results of an experiment in which swath cured sorghum hay lost 11.1 per cent of its weight in 4 hours while similar hay windrowed at once lost only 6.6 per cent. Willard (81), Westover (80), and Kiesselbach and Anderson (36) (37), have recently conducted experiments to determine the degree to which the leaves aid in drawing moisture from the stems of curing hay plants. Willard concludes that, "In alfalfa, the leaves have no tendency to dry the stems", but that "Soybean leaves had a tendency to dry the stems". Westover concludes that, "In every case where the leaves were picked from the stems, the alfalfa dried out more rapidly than when allowed to cure in the natural state". Kiesselbach and Anderson conclude, "There was no indication in the tests covering a period of five years that the leaves functioned materially in the withdrawal of the moisture from the stems during the curing period".

The observation of partially wilted plants in the field in the afternoon has led many to believe that hay cut at this time would have much less water to lose in the curing process than hay cut in the morning. This idea may be justified with certain plants. Livingston and Brown (41) working with different plant species found growing in the desert have reported differences between the high moisture content and the low. the decrease from the maximum amount of water in a 24-hour period in various plants was: 39.1; 38.6; 37.0; 36.5; 28.9; 16.0 and 14.5 per cent.

Maximov (45, p.222) reviews the literature on the diurnal water deficit of plants and shows that there is a range of from 40 per cent to less than 1 per cent. He points out the fact that the difference between the low and the high moisture content will depend on the environment. Mason and Maskell (44) found that the moisture content of the cotton plant at various times of day was best determined by using the residual dry weight rather than the fresh weight of the material as a basis on which to figure the moisture per cent.

Kiesselbach and Anderson (36,p.83) cut composite 300 to 500 gram samples at hourly intervals, from 8 A.M. to 5 P.M. The experiment was first performed on August 5 and repeated on August 6 and on August 8. As an average for the three years, the high moisture content of 72.7 was found at 8 A.M. and the low, of 69.5 per cent at 4 P. M., with a gradual loss from 8 until 4. They state that this difference probably is not of sufficient importance to be considered a very material factor in the curing processes.

Bakke and Henson (2) determined the moisture content of alfalfa plants in the field each hour, from 8 A. M. until 6 P.M. on June 23, July 12 and August 5, 1927. In general, the moisture content of the plants decreased until 11 A.M. after which it rose slightly until 1 P.M. then decreased gradually until 4 P.M. after which it rose slightly.

The behavior of the stomata of the alfalfa plant during the curing process has not been investigated fully, though some studies have been made on the plants in the field.

Loftfield (43, p.18) has pictured stomatic changes during a 24-hour period. He finds the stomata of the upper and lower surfaces of the leaf behaving similarly. The cycle of movement during normal growing conditions is as follows. The stomata close at 7 to 8 P.M. and remain in this condition until 10 or 11 P.M. when they may open slightly continuing in this condition until 3 to 4 A.M., at which time a slow but gradual opening ensues until full opening is reached at 7 A.M. At times the stomates close at least partially at 10 or

11 A.M., then open again by 1 or 2 P.M., after which the openings gradually close until completely closed at 7 P.M. Loftfield notes a daily variation in the time of opening or closing due to temperature and humidity conditions, and to the supply of soil moisture. Under unfavorable conditions, such as protracted drouth, Loftfield (43,p.45) notes that the stomata are open at night and closed throughout the day.

The question as to whether or not the closure of the stomatic openings serves to regulate the rate of transpiration has been investigated by Darwin, Kohl, Lietgeb, Schwendener, Merget, Mohl, and others. All of these workers, according to Loftfield, infer a considerable direct control of transpiration by the closure of the stomatic openings. The work of Muenscher (56),Lloyd (42), and Trelease and Livingston (74) has tended to cast some doubt as to the regulatory action of the stomata on the loss of water vapor from the plant. Lloyd (42,p.31) points out the possibility that partially closed stomata may not influence transpiration owing to the increased rate of diffusion through the narrower openings, as has been shown by Brown and Escombe (7).

Loftfield (43,p.101) believes there is a very close relation between the rate of transpiration and the degree of opening of the stomata. He points out that the action of the factors of evaporation overshadow the effect of the condition of the pores of the stomata when the pore is more than 50 per cent open, but that when the closure is almost complete the regulation of the water loss by the degree of opening is very close, and even small changes in the degree of opening may overshadow the other factors of evaporation.

Darwin (20), on the basis of results secured with a horn hygroscope inferred a temporary opening of the stomata in the first three to ten minutes after cutting followed by a slow gradual closing.

Lloyd (42,p.83) measured the pores of the stomata at very short intervals after cutting and found them to close gradually during the first 15 minutes with no tendency to open wider during that period. Lloyd did not follow the stomata beyond this first closing period.

Maximov (45,p.215) gives a critical review of the views of physiologists in this and European countries. He believes that the closing of the stomata, the slowing down of transpiration, and the decrease of the water content of the leaf are not directly related, as cause and effect, but that all three are due to a common cause, which is the condition of the water supply of the plant.

Experiments in methods of curing hay have been rather difficult to complete as there has been no satisfactory method of judging the degree of curing in the fields. The usual method of determining the moisture content has been by the use of shrinkage samples taken during the progress of the experiment, but yielding their information only after 4 to 48 hours delay. Only one extensive test which attempts to measure the progress of the curing in relation to time has been reported. This is the work of Kiesselbach and Anderson (36).

In order to make an estimate of the degree of curing, or the moisture loss of the hay in the field as the work progressed, Kiesselbach and Anderson filled tarlatan bags with hay, weighed them and placed them in the windrow, swath or cock. By assuming that the hay in the bags cured similarly to the loose hay, they could obtain an idea of the moisture content of the loose hay by reweighing the small bags at intervals and calculating the moisture loss. They also took representative shrinkage samples of the hay at 7 and 10 A.M. and at 1 and 4 P.M. and determined the moisture content in the usual way. The tarlatan bags were weighed at each time of sampling and then replaced. In summarizing their work, the hours required to reduce the moisture content of the hay curing under the various methods to 30 per cent has been calculated as given below:

1. Swath curing throughout.	(27)
2. Windrow curing throughout.	(65)
3. Cock curing throughout.	(102)

4. Swath curing until beginning to wilt then windrow cured for remainder. (50)
5. Swath curing until well wilted then windrow cured for remainder. (53)
6. Swath curing until 2/3 cured then windrow cured for remainder. (44)
7. Swath curing until beginning to wilt then cocked. (45)
8. Swath cured until well wilted then cocked. (29)
9. Swath curing until 2/3 cured then cocked. (29)

Experimental

The experimental work on methods of curing has been confined to alfalfa. This crop is more susceptible to injury either from under or over-curing than are grass mixed hays and the alfalfa crop is generally recognized as requiring extreme care if the best quality of hay is to be produced.

Methods of Procedure.

The Field.

An 8-acre field of alfalfa was seeded to northern grown, variegated alfalfa in the fall of 1926, for use in the study of methods of curing alfalfa hay. An excellent stand was secured, except a small corner of the field, which was reseeded in the spring with excellent results, so that after 1927, a rather uniform 8-acre field of alfalfa was available for the study. The soil was rather fertile uniform bottom land on the farm of W. F. Templeton located about two miles southeast of the College. In addition to this field, plots of alfalfa in College Field were made available for use in the study of the moisture content of the plants in the field at each hour of the day and for the observation of stomatal behavior and leaf function in the curing of hay.

Methods and Materials for Studying the Rate of Curing.

The usual method of determining the moisture content or the degree of curing in experimental work is by taking shrinkage samples of the material. Three bags varying in size from about 5 pounds of fresh cut hay to 2 pounds of cured hay are usually used. These are weighed immediately, dried out completely and reweighed. Often the material is air-dried, weighed, then ground, and representative samples completely dried in an oven. The original moisture content is determined from the loss in weight.

It is evident that considerable time must elapse from the time of sampling until the moisture content can be known. This delay renders the use of such a method impractical where the next operation in curing is to be introduced at a particular stage in the process. For our work it was necessary that the degree of curing should be known throughout the curing process.

Construction and use of Weighing Device.

Several ideas were tested in preliminary work in attempting to arrive at a satisfactory method of determining the moisture content of curing hay in the field. The idea finally adopted involved the use of a device which enables the operator to arrive at the moisture content by weighing the same, rather large amounts of hay at desired intervals while leaving the hay in its normal exposure. By calculations based on the loss of weight, it is possible to arrive at an approximation of the moisture content at any time during the curing process. Three models of such a device have been used in our work.

The first model designed by the author consisted of two comb-like frames, with teeth five feet long, placed 8 inches apart. The details of the construction of this device may be seen in the illustration Fig. 1. The long bamboo poles serve to prevent the downward tipping of the teeth when a load is being weighed. The rack is lifted by a harness of ropes attached at four points on the frame. In the use of this device, one of the racks is slipped under the hay from one side and the other from the opposite side. The two halves of the rack are lifted and lowered simultaneously in the weighing. After the weighing the racks can be slipped from under the hay without disturbing its arrangement. This device was used for weighing single ten-foot swath sections, or windrow sections, and the lighter cocks of hay.

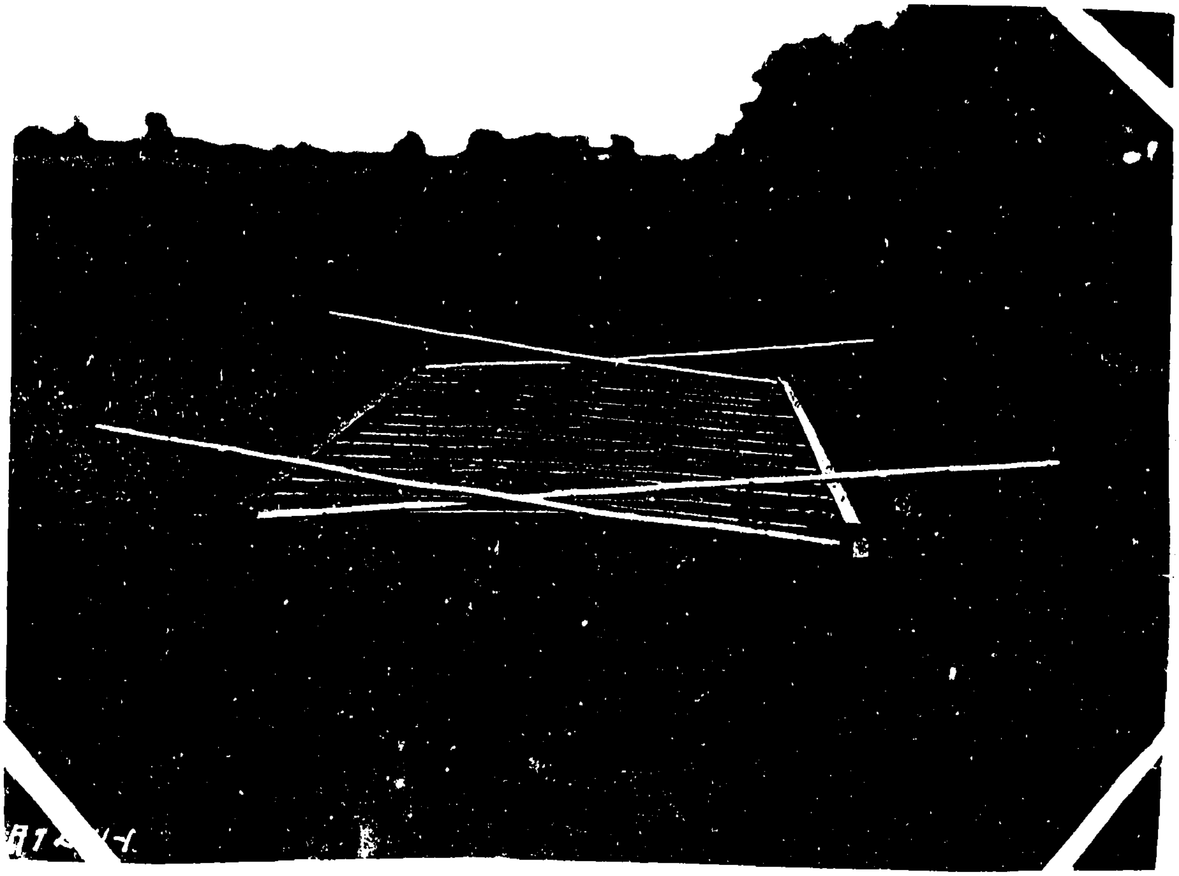

Figure 1. Original device used for estimating the degree of curing of hay in the field.

The first device proved too fragile and was replaced by one designed largely by Professor F. S. Wilkins. The second device was made 10 feet long and with teeth long enough to slide under two swaths of hay at a time. The teeth were of fir $1\frac{1}{4}$ inches square at the base and tapering somewhat toward the outer end. For lifting, a 1" by 5" was placed under the end of the teeth after the rack had been slid under the hay. The two outside teeth had holes in them near the end and these were slipped over two studs in the end of the 1" by 5" piece. The hoist and scales were used as before. The rack was a great improvement in that it took a larger area, could be rapidly inserted, weighed and removed without changing the position of the hay in the swath or windrow. Its sturdy construction also permitted its use on larger cocks of hay. Three men could insert the rack, make the weighing and remove it in about half a minute. The construction of this rack is shown in Figure 2. together with the harness and hoist for lifting.

The device in operation, weighing a swath of hay, is shown in Fig. 3.

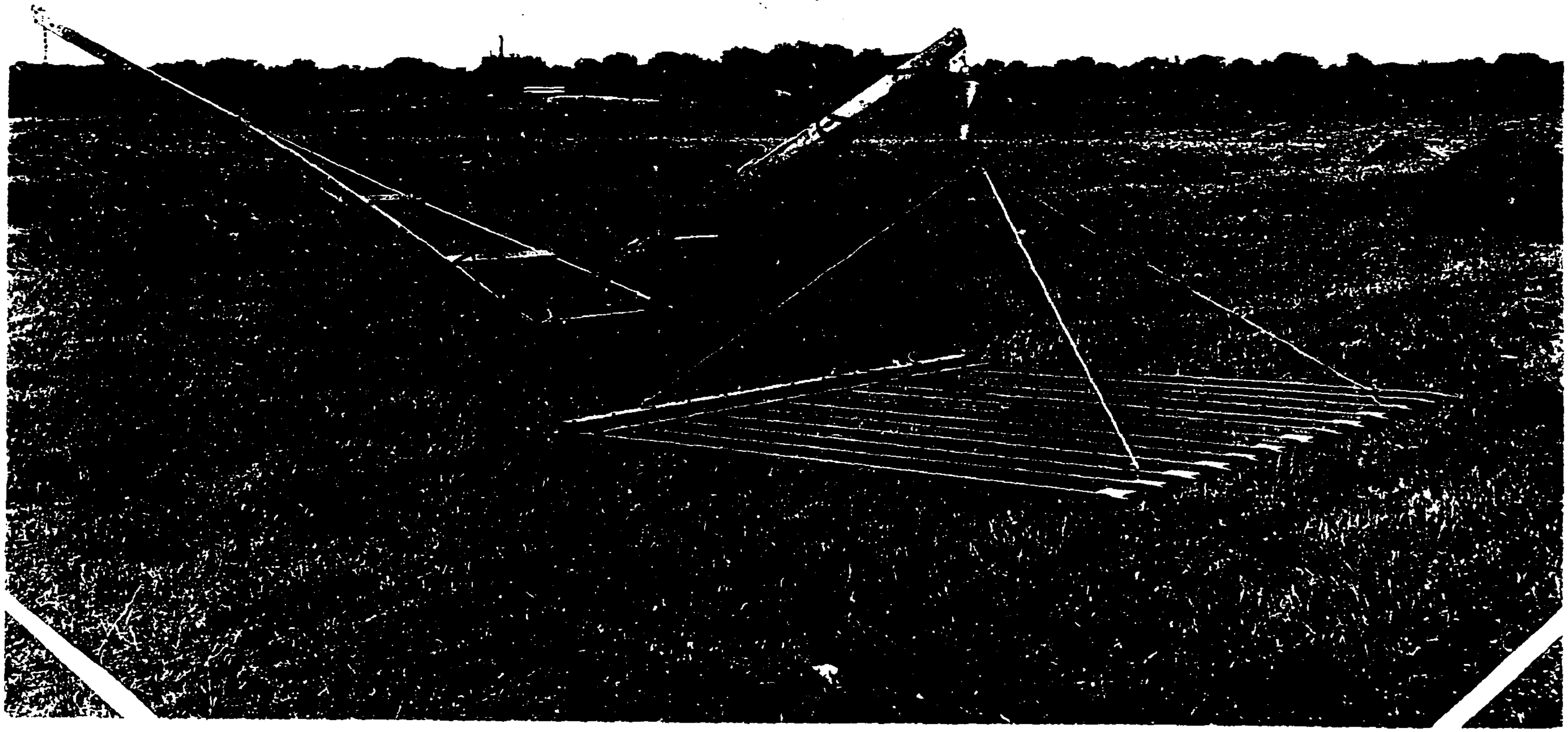

Figure 2. The Weighing Device and Cart Hoist used in the Field Studies of methods of curing hay.

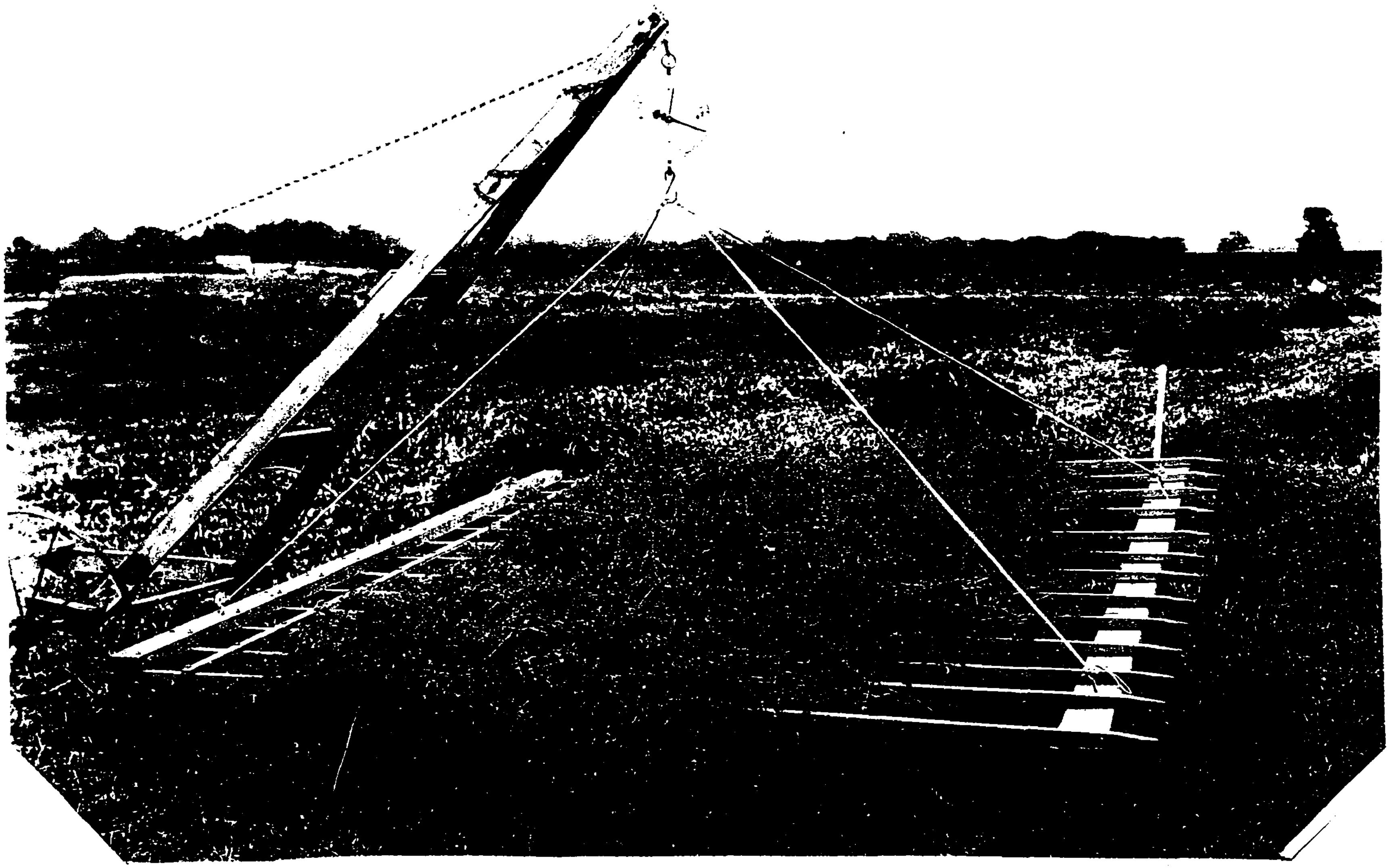

Figure 3. The Weighing Device in operation
weighing a swath of hay.

A third weighing device of the same general type was constructed, on a smaller scale, so that one man might operate and record the weights. This device has a rigid frame, rigid teeth 5 feet long and an iron bar, for lifting, connected solidly with the frame and bent over the load with suitable notches for the adjustment of the scale. A two-legged rest, and a lever across the top with the scales on one end, enables one man to lift the rack and read the weight on the scale. This device which is shown in Fig. 4., will weigh a 5-foot section of swath or windrow.

The use of these weighing devices involves either an estimate of the moisture content at the time the hay is cut or an actual moisture determination at this time. The usual procedure adopted for these studies was to determine the moisture content of representative samples of the hay to be harvested for several days in sequence, prior to the day of cutting. With this information in mind, the moisture content was estimated on the day of cutting with sufficient accuracy for the early part of the curing work. Moisture determinations were made on the hay at the time of cutting by drying samples in an oven. The weights used in the experimental data presented are based on the known moisture content.

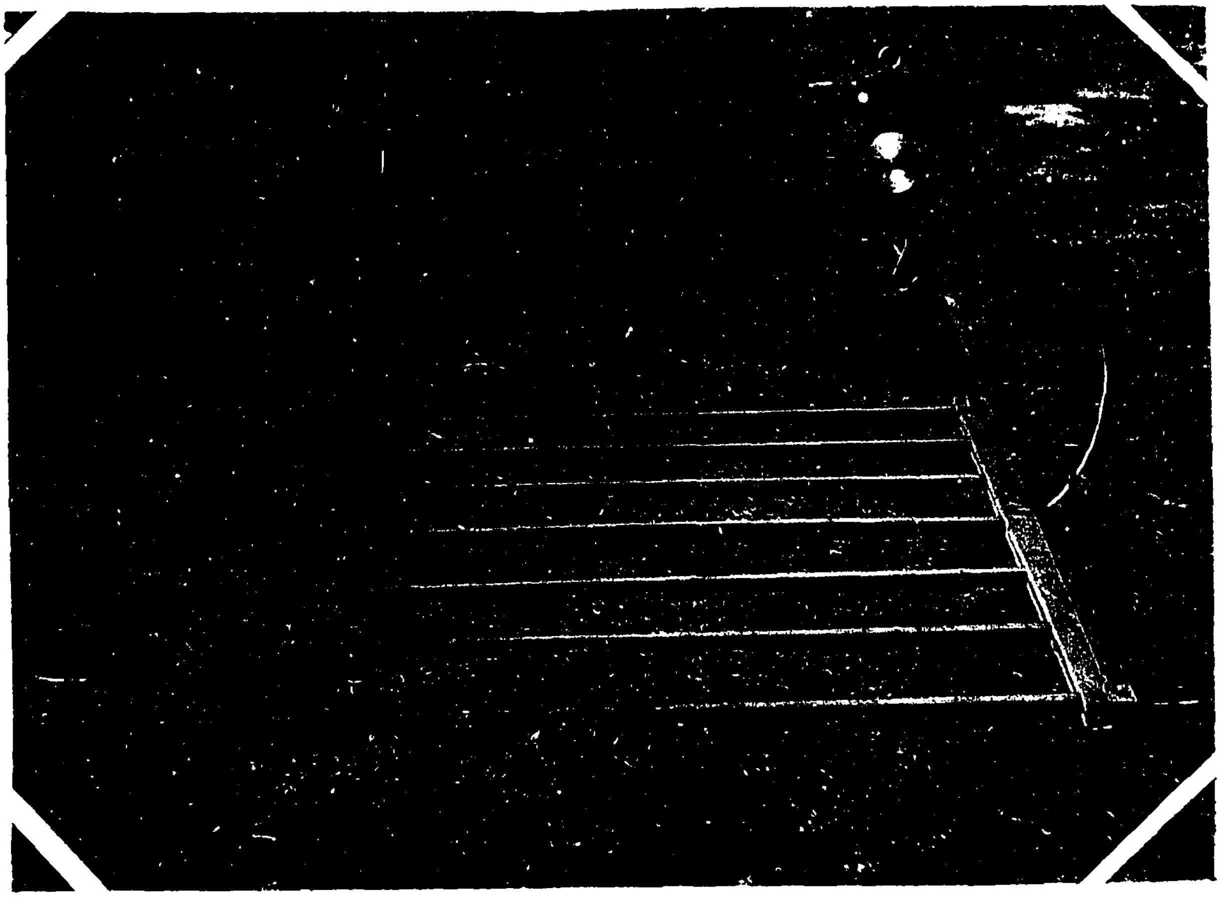

Figure 4. The Weighing Device designed to be used by one man. This device weighs only 10 pounds.

The procedure in the use of the rack consisted of weighing three areas of hay at the start of the cutting and another set of three at the end of the cutting. The loss in weight for these areas, as shown by weighing the same areas at intervals throughout the period of curing, permitted rather accurate estimates of the degree of curing of the hay at any time and a close determination of the stage of one-fourth, one-half and three-fourths swath cured for the inception of new methods of curing. As soon as the cutting was completed part of the hay was windrowed. Areas were weighed in these windrows, and by subsequent weighings of these areas the moisture content of the windrowed hay could be known at any time.

In order to facilitate the calculations of the moisture content at subsequent weighings, a chart, suggested by Professor F. S. Wilkins, was constructed which enabled one to read directly the moisture in the hay at any weighing. This chart was limited in scope of use as there were two variables, the moisture content of the hay at the start and the weight of a rack load of hay. The chart was constructed for rack loads of hay varying from 30 to 14 pounds by two-pound intervals and for moisture contents of from 68 to 73 per cent. In order to include all possibilities a very extended chart would have been required.

The use of the rack was checked by the following procedure. Hay was cut and a portion windrowed at once. Three areas were weighed immediately in both the swath and the windrow and three five-pound shrinkage samples taken in each. The weighing, and the taking of the shrinkage samples was repeated every two hours during the curing of the hay. The results of this comparison are given in Table II. The relationships between the two methods of arriving at the moisture content of the hay is shown in the graph in Figure V.

A study of the data in Table II indicates that the weighing device gives a more uniform picture of the condition of the hay than is secured from shrinkage samples. With the shrinkage samples, gains of as much as four per cent occurred at succeeding samplings when one would feel certain that there had been a loss. It would appear difficult to sample half-dried hay in the windrow with accuracy; swath cured hay seems to cure out more evenly and successive shrinkage samples do not appear so erratic. Green hay may be samples rather accurately by the use of shrinkage samples. Half-dried or windrow-cured hay is difficult to sample accurately, as shown by the extreme variations toward the latter part of the test.

Table II. Percent of moisture as estimated from weighed areas compared with determinations made on oven dried shrinkage samples, 1927.

Time		Swath Curing		Windrow Curing	
Day	Hour	Weighing Device	Shrinkage Samples	Weighing Device	Shrinkage Samples
Aug.22	9:00	69.70	69.70		
	10:00	66.29		66.29	66.29
	12:00	62.50	65.29	63.50	66.22
	2:00	57.0	55.09	61.32	62.52
	4:00	53.0	51.21	57.5	57.96
	6:00	52.0	52.15	56.5	56.69
Aug.23	1:00	46.5	42.24	54.0	55.47
	3:00	43.0	40.14	49.5	48.95
	5:00	39.0	36.42	45.0	44.05
Aug.24	10:00	38.0	35.37	39.5	40.76
	12:00	31.5	31.72	36.5	44.02
	2:00	27.5	27.41	33.0	31.04
	4:00	24.0	24.54	29.0	33.26
	6:00	21.0	25.75	27.0	28.32
Aug.25	11:00	19.0	19.37	25.0	25.23
	1:00	18.5	18.55	24.0	26.56
	4:00	17.6	16.31	22.5	18.25

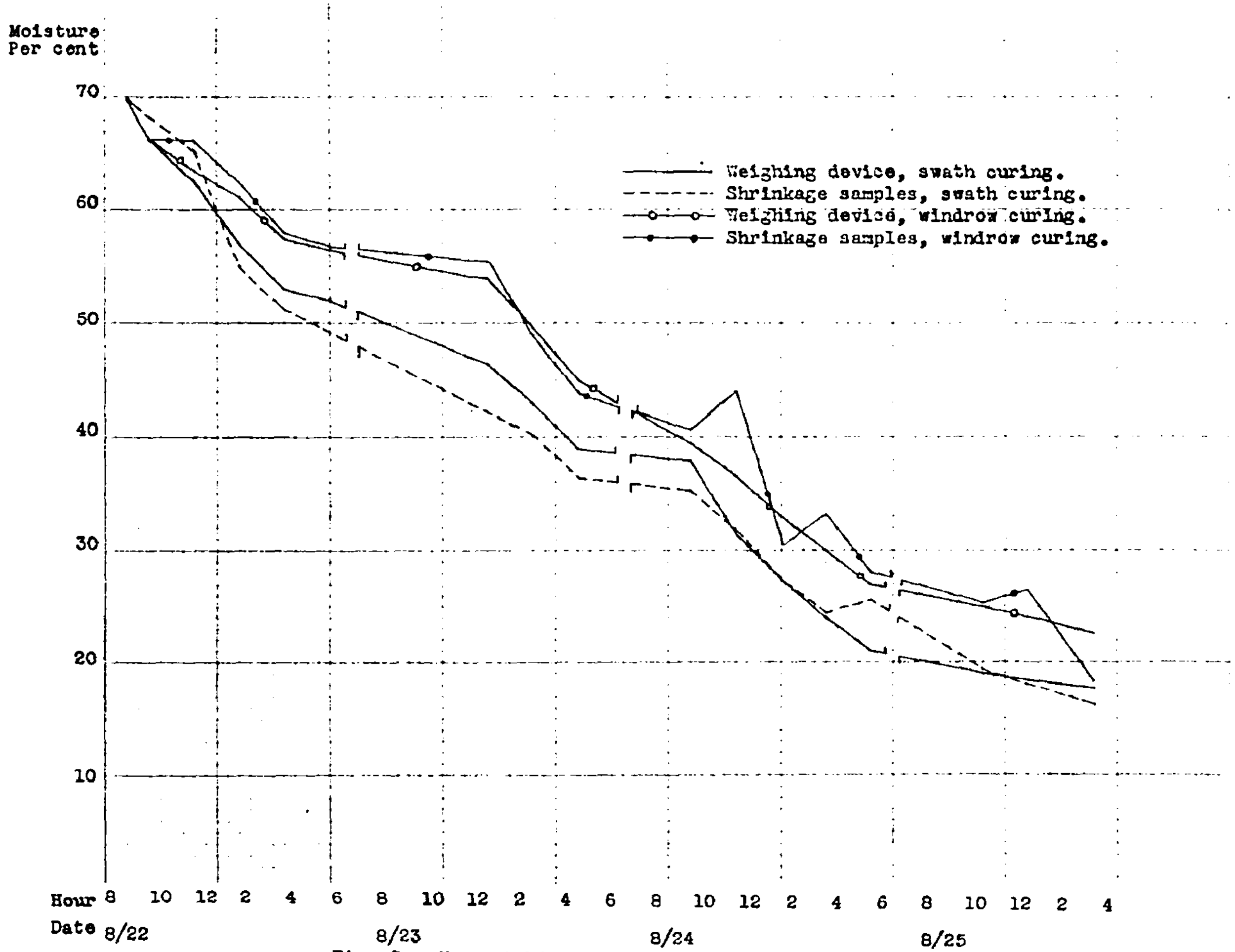

Fig. 5. The weighing device as a means of determining the moisture content of alfalfa hay curing in the field as compared with the determination of the moisture by taking three shrinkage samples at two hour intervals. Series of August 22, 1927.

Shrinkage Samples.

Eight-ounce cotton bags were used throughout the test for taking shrinkage samples. Samples were taken at the time of cutting, of weighing, of raking, at the time of the inception of any new method of curing, at the end of each method in the series, and when curing was discontinued. The procedure followed was to take samples in triplicate and weigh at once. Samples were dried rapidly to a constant weight then representative ones were ground, weighed and dried in an oven at 100 degrees C. for 48 hours and the original moisture calculated. The shrinkage sample moisture determinations were used as a check on the estimates made possible by the weighing device.

Methods and Materials for the Study of Stomatal Behavior and Leaf Function in Curing Hay.

In the study of stomatal behavior, the method described by Lloyd (42), in which pieces of the epidermis are torn off then placed in absolute alcohol, was used. The alcohol draws out the water quickly without appreciably changing the position of the stomatic openings. Attempts were made by the use of water screens to study the condition of the stomata relative to degree of opening with the whole leaf under the microscope in sunlight. This method was not suitable on account of the difficulty in observing exact condition of the opening with so much extraneous matter present.

Three separate methods were used in checking the influence of the leaf on the loss of moisture from the stem in the curing plant. A duplication of the experiments of Willard, Westover and Kiesselbach and Anderson was made by clipping the leaves from the stems of some alfalfa plants and exposing the stems and leaves along side of normal plants, weighing at frequent intervals to determine the moisture loss. A second test was made in which the leaves were removed from top or bottom portions of the plant and the influence of the remaining leaves on the stripped portion and on the portions under the leaves compared with whole plants and with plants having the reverse portion stripped of leaves. A third test was made in which the rate of drying was studied in samples consisting of (a) top leaves, (b) top stems, (c) bottom leaves, (d) bottom stems, (e) top stems with leaves attached, (f) bottom stems with leaves attached and (g) the whole plant. Screen trays with covers were used which could be weighed and replaced without danger of leaf loss. Weighings were made on a scale graduated to 1/500 of a pound which could be read to 1/1000 of a pound.

Results of Experiments

Variation in the Moisture Content of the Alfalfa Plant at Different Times of Day.

The moisture content of alfalfa in the field was determined hourly from 8 A. M. to 8 P. M. Triplicate one-pound samples were cut and weighed immediately, taken to the laboratory, dried, weighed, ground and the remaining moisture determined by oven drying. The average moisture content of the three samples for each hour of the day is given in Table III. The experiment was repeated on four different days. On July 19 the plants were young, just beginning to flower; on August 5, they were about one-third in bloom; August 20 and August 21, one-half in bloom. The hourly temperatures and the humidity were high. A light rain fell during the night of the 20th. On August 21 a relatively high temperature and relatively low humidity, with a good breeze, provided good drying conditions.

In the study of the moisture content of the alfalfa plant at different times of the day, the low moisture content was reached at 11 A. M. on the two normal days. After this period there was a slight rise, then a downward trend to 3 P. M. in one case and 4 P. M. in the other, from which points the moisture rose again to 8 P. M. The extreme

Table III.

The Variation in Moisture Content of the Alfalfa Plant Growing in the Field at Hourly Intervals, 1928.

Time of Sampling	Moisture Content of the Alfalfa Plant and Hourly Temperature.					
	July 19	Aug.5	August 20		August 21	
	Moisture per cent	Moisture per cent	Temp. F.	Moisture per cent	Temp. F.	Moisture per cent
8 A.M.	78.2	74.3	75	73	68	74.0
9 A.M.	77.7	73.5	76	73	71	73.8
10 A.M.	77.0	72.6	78	72.6	72	73.8
11 A.M.	75.9	71.8	78	72.0	75	73.2
12 A.M.	76.3	72.2	79	71.6	75	71.5
1 P.M.	77.0	73.5	80	72	77	71.2
2 P.M.	76.9	72.6	81	72	78	70.2
3 P.M.	76.0	72.9	84	72.5	79	70.
4 P.M.	76.4	72.5	85	72.4	79	71.
5 P.M.	76.5	72.7	87	73.2	77	72.3
6 P.M.	76.2	72.6	86	73.6	76	73.6
7 P. M.	75.8	72.8	80	74	75	72.8
8 P. M.	77.0	73.6	73	74.2	73	73.4

Relative Humidity, 12 noon 74 45

variation in moisture from the low to the high point, was 2.4 per cent in the first and 2.5 per cent in the second trial. This difference,which represents both loss of water and gain in photosynthate, is not an important factor in determining the time of day to cut the hay.

On August 20 an increasing cloudiness and a high humidity caused an earlier rise in moisture content in the afternoon, even with the high temperature prevailing at this time. On August 21 the low point in the moisture content was not reached until 2 o'clock, probably because of a gradually lowering relative humidity after the light rain of the previous evening. These data agree very well with those obtained by Kiesselbach and Anderson (36). The low point in the moisture content of the plant did not occur in their studies until 3 or 4 P. M. yet in practically every case, the moisture content was lower at 11 or 12 than at 1 or 2 in the afternoon.

This fluctuation in moisture content may be due to the observed changes in stomatic openings which occur on days with rapid evaporation. Loftfield (43) has observed stomates open at 7 A. M. closing gradually until they are closed at 10 or 11 A. M. and then opening again later in the afternoon, reaching their second open stage at 4 P. M., after which they close again by 7 P. M. He has also observed, with still more severe drying conditions, a closed state at 7 A. M. which continued throughout the day, and an opening which started at 10 P. M. and continued until 5 or 6 A. M., at which time they began to close again.

The time of cutting of other plants for hay may be influenced by the partial wilting in the afternoon. The extremely large differences observed by Maximov (45, p.225), Livingston and Brown (41) and others, between the high and low moisture contents in a 24 hour period, would indicate that for certain conditions and certain plants the time of day to cut for hay might be determined by the time of the low moisture content. These workers have shown differences of as much as 30 to 40 per cent between the low and high moisture content of the leaves of the same plant in a 24 hour period.

The Influence of Method on the Rate of Curing of Alfalfa Hay.

The experimental work on methods of curing includes a comparison of twenty-eight separate methods of handling the hay. These methods of curing are grouped under the following five experiments.

A. The rate of curing hay windrowed immediately compared with complete swath curing and with cocking immediately.

B. The rate of curing hay in the windrow compared with partial curing in the swath, followed by windrow curing.

C. A comparison of the rate of curing of alfalfa hay in the windrow and in the cock when the cocking is done after partial swath curing.

D. The rate of curing hay in windrow with and without turning.

E. The rate of curing hay in the swath, with and without tedding.

The first cutting of hay in the methods of curing experiments was made July 6, 1927. The hay cut at this time was used as a preliminary series designed primarily to test the weighing device with reference to the time required to make the weighings. In the preliminary work the hay from 10 areas was weighed in each method of curing to be tested. This number of weighings was found to be too large as this necessitated 280 weighings every two hours when a complete series was being tested.

The field weighings from which the moisture content was calculated were made rather continuously throughout the study. The moisture content of the hay is calculated from the average of the three or five weighings made in each method of curing. In order to present the data in a reasonably compact table the original weights were used for the moisture calculations after which the moisture calculations were plotted on the graph. The figures presented in the tables, then, are the exact weights and the moisture content in cases where the weighing occurred on the even hour and an interpolated figure arrived at by calculation from the graph where the weighing was not on the even hour. The actual field weights, and the moisture determinations from which the calculations were made are given for each series in the appendix.

A. The Rate of Curing Hay Windrowed Immediately Compared with Complete Swath Curing and With Cocking Immediately.

Four series were completed comparing the rate of curing in swath, windrow and cock. The first series was started on July 7, the second on July 8, the third on August 22 and the fourth on August 23. The weather conditions for the period of July 7 and 8 is given in Table IV and for August 22 and 23 in Table V.

Table IV.

Weather Observations for the Period,
July 7 to 11, Inclusive, 1927.

Month	Day	Temperature - Fahrenheit Mean: A.M.	Mean P.M.	Maximum	Minimum	Mean 24-hour
July	7	72.4	80.6	87	62	72.9
	8	74.6	83.8	88	57	74.7
	9	78.6	86.5	89	64	77.3
	10	80.2	89.8	92	58	78.5
	11	90.4	96.8	95	69	86.0

Month	Day	Relative Humidity 7 A.M.	Noon	7 P.M.	Prec. in.	Wind Velocity Mi per hr	Per cent possible Sunshine
July	7	74	55	50	0	7 to 12	66
	8	74	44	42	0	6 to 14	85
	9	60	38	33	0	7 to 14	100
	10	76	36	30	0	3 to 7	100
	11	58	28	21	0	8 to 17	96

Table V.

Weather Observations for the Period
August 22 to August 26, 1927.

Month	Day	Temperature - Fahrenheit: Mean 8-12 A.M	Mean 1-6 P.M	Maximum	Minimum	Mean 24 hr.
Aug.	22	75	78.3	80.0	63.0	70.7
	23	67.0	73.0	74.0	53.0	65.2
	24	66.0	73.3	76.0	44.0	64.1
	25	70.6	76.5	80.0	57.0	68.1
	26	70.0	77.1	79.0	50.0	67.6

Month	Day	Relative Humidity: 7 A.M. per cent	Noon per cent	7 P.M. per cent	Precip. inches	Wind Miles per hr.	Per cent possible sunshine
Aug	22	80	50	83	0	7-16	71
	23	84	47	49	0.04	7-12	93
	24	75	43	50	0	3- 6	53
	25	79	49	50	0	4-11	88
	26	83	34	48	0	6-18	100

The general method of procedure after cutting the hay was to weigh the hay from three, 10-foot double swath areas immediately for the swath curing and rake two swaths into a windrow with a side delivery rake and weigh three areas in this for the windrow curing. Two additional windrows raked at once after cutting were cocked, one-half of the cocks small in size and the others medium. Three cocks of each size were weighed. The small cocks were the typical western type of alfalfa cocks, consisting, when cured, of one medium to 2 small fork-fulls of hay. The medium sized cocks were about five times as large as the small cocks. The hay from each area was reweighed at two-hour intervals and triplicate shrinkage samples of the hay taken at the beginning and at the end of curing by each method.

Series of July 7. The procedure described above was followed for this series except that five instead of three areas were weighed in each method of curing. The hay was cut for this series between 7:50 and 8:10 A. M. Each method of curing was tested on two, five-foot six inch mower swaths, the areas totaling approximately 100 yards of swath. The alfalfa for this series was of the previous years seeding. The plants were 18 inches high, erect, leafy and sparsely branched. The stage of maturity would be described as about one-tenth in bloom.

The results of this experiment are given in Table VI. The data presented are averages for the five areas. The method of calculation used consisted of determining the dry matter in the original weight of the areas, then at each subsequent weighing the dry matter was subtracted from the new weight and the remainder divided by the new weight to give the moisture content at that time. In order to further picture the relationship between the methods of curing, the moisture content of the hay under each method of curing is shown graphically for the period of the experiment in Fig. 6.

In the series of July 7, a study of Figure 6 clearly shows that alfalfa hay loses moisture more rapidly if left in the swath than if windrowed at once. The swath cured hay reached 30 per cent moisture three hours before the hay in the windrow reached the same degree of curing. It will also be noted that the hay spread out in the swath overnight absorbs more moisture than hay in the windrow or in the cock when heavy dews form. A similar marked advantage in the rate of curing of hay in the windrow as compared with hay curing in either the small or medium sized cock is noted. The small cocks lose moisture

Table VI.

The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when windrowed immediately after cutting, as compared with complete swath curing and with cocking immediately. Series of July 7, 1927.

			Windrowed Immediately		Swath Cured Completely		Hay Cocked at once			
							Small Cocks		Medium Cocks	
Month	Day	Hour	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent
July	7	8	29.9	67.00	15.9	67.00	31.4	67.00	79.1	67.00
		10	27.0	63.50	14.25	63.00	30.5	66.00	76.8	66.00
		12	25.0	60.5	12.2	57.00	27.7	62.5	72.5	64.00
		2	23.5	58.0	10.8	51.50	25.6	59.5	68.7	62.00
		4	21.5	54.00	9.9	47.0	24.1	57.0	64.5	59.5
		6	19.7	50.0	9.8	46.0	22.8	54.5	63.7	59.0
July	8	8	18.3	46.07	10.0	47.30	22.3	53.5	61.5	57.5
		10	17.1	42.5	8.2	36.0	21.4	51.5	60.0	56.5
		12	15.7	37.0	7.3	28.0	19.9	48.0	57.4	54.5
		2	13.9	28.99	7.0	24.71	18.4	43.5	54.9	52.5
		4	12.6	21.6	5.8	9.14	17.1	39.5	51.7	49.5
		6			5.8	9.00	16.1	35.5	49.7	47.5
July	9	8			6.0	12.17	15.3	32.0	47.5	45.0
							14.7	29.5	47.0	44.5

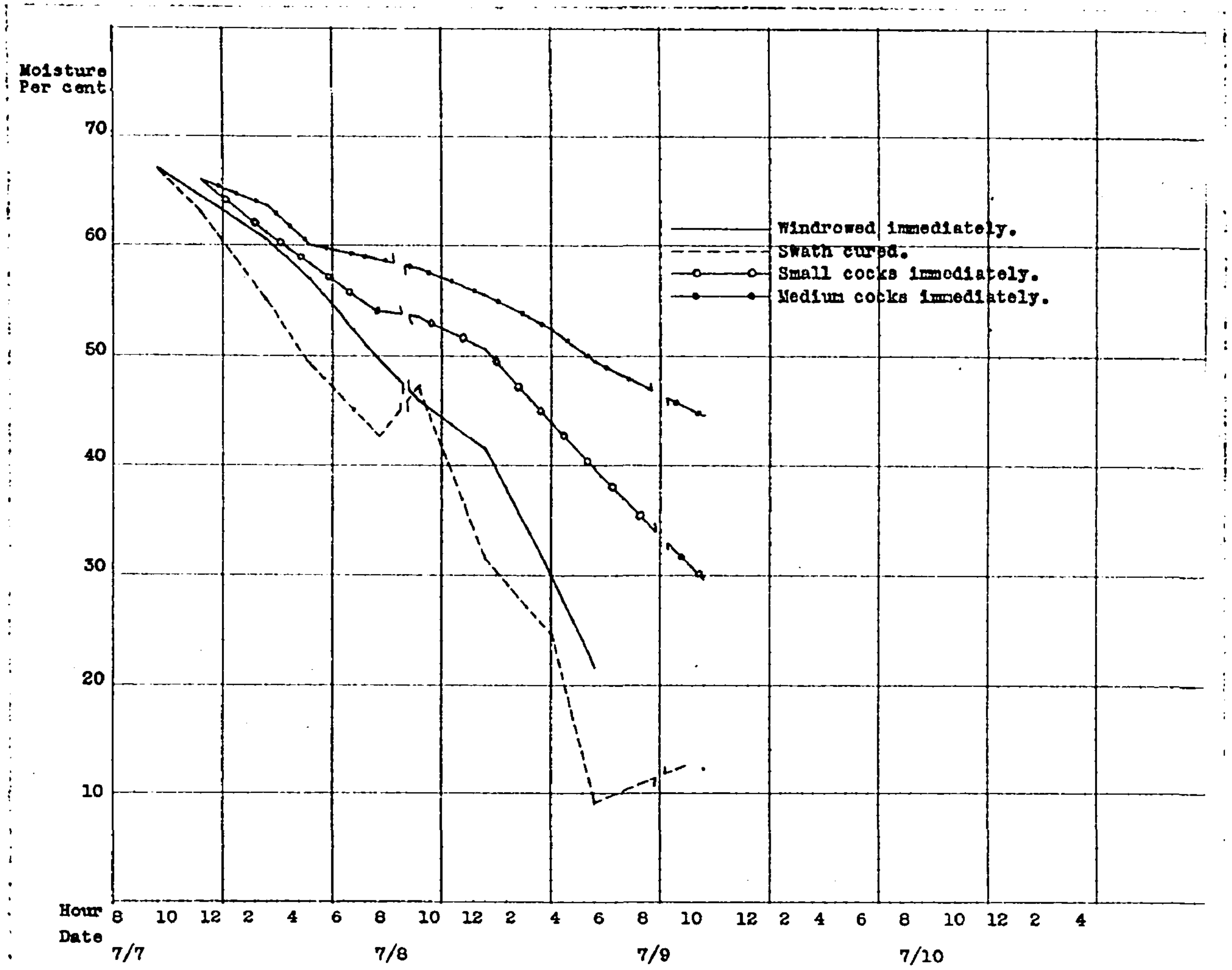

Fig. 6. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when windrowed immediately after cutting, as compared with complete swath curing and with cocking immediately. Series of July 7.

at an increasingly greater rate than the medium sized cocks. The small cocks were field cured in two-thirds the time required for the larger cocks. The medium sized cocks of green hay heated to such an extent that the green color of the hay was lost in the center of the cock.

Series of July 8. The alfalfa used for this series was a mixture of fall and spring seeding and had a slight mixture of oats. The oats were in the milk stage of development and the alfalfa was an equal mixture of plants, one-half of which were about one-tenth in bloom and the other half about 16 inches high with no flower buds showing. The test was identical with that of July 7 except that the hay from three areas was weighed for each method instead of five, and the medium sized cocks were not included. With five areas for each method, for the 28 comparisons of a complete series, 140 weighings every two hours would have been required. This number of weighings had proven to be too many.

The hay was cut between 9 and 10 A. M. The areas were weighed at 10 A. M. in each of the three methods. The averages of the three weights for each method of curing are given at two-hour intervals in Table VII. The moisture content of the hay under each method is shown graphically

Table VII.

The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when windrowed immediately after cutting, as compared with complete swath curing and with cocking immediately. Series of July 8, 1927.

Month	Day	Hour	Windrowed Immediately		Swath Cured Completely		Cocked at once Small Cocks	
			Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent
July	8	8						
		10	31.3	60.5	22.3	59.7	39.8	59.7
		12	28.3	56.32	19.4	53.66	37.1	56.77
		2	24.9	50.5	16.1	44.0	33.8	52.5
		4	22.2	44.5	14.1	36.5	31.1	48.5
		6	20.6	40.0	13.2	31.89	29.4	45.5
July	9	8	19.3	35.96	11.9	24.45	28.5	43.72
		10	17.5	29.37	11.8	23.81	26.8	40.15
		12	16.8	26.50	11.4	21.14	25.7	37.50
		2	16.6	25.75	11.3	20.5		
		4						
		6						

for the period of the experiment in Fig. 7.

In the series of July 8, the hay cured out much more rapidly than that of July 7 on account of a two degree higher temperature and 10 per cent lower relative humidity. Both the sunshine and the wind were somewhat more favorable on July 8 for drying hay. The swath curing hay was reduced to 30 per cent moisture in 9 hours while the windrow curing hay required 12 hours of curing time and an overnight period. This 30 per cent moisture is near the upper limit for field cured hay. In calculating the time required for curing only the elapsed time between 7 A.M. and 7 P.M. is included as this is believed to represent most accurately the drying hours. The small cocks were 4 hours behind the windrow curing hay in reaching 40 per cent moisture. The relative humidity decreased toward evening and no marked increase in moisture on account of the dew is evident on any of the hay in this series.

Series of August 22. The hay for this series was an excellent stand of leafy alfalfa 22 inches high and about one-third in bloom. The series was started on a clear morning but the sky became overcast and a light sprinkle of rain fell at 5:30 P. M., and which was followed by a light rain in the night. The series of

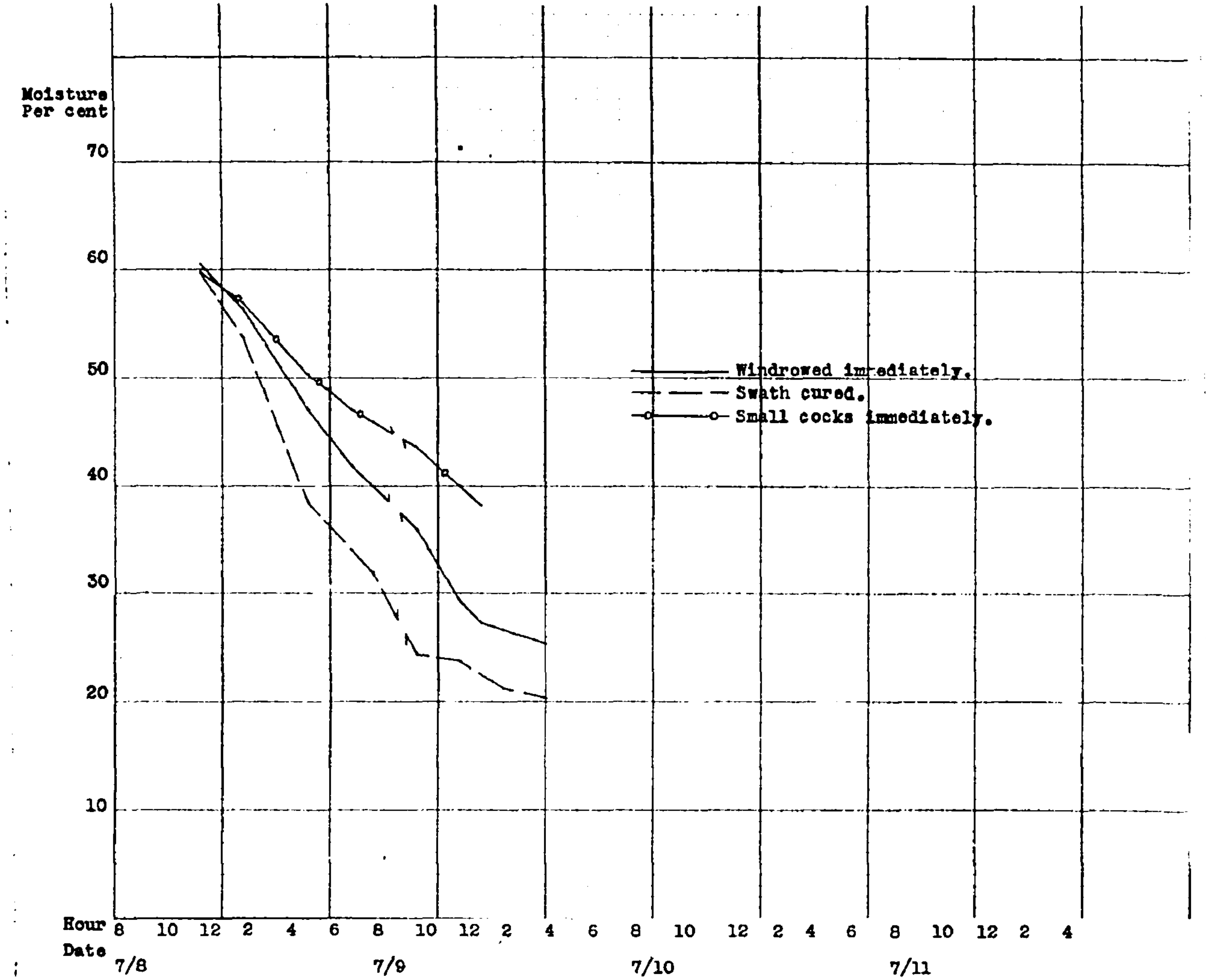

Fig. 7. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when windrowed immediately after cutting, as compared with complete swath curing and with cocking immediately. Series of July 8.

methods compared were the same as those during July 7. The results of this study are presented in Table VIII. The moisture content of the hay for each method is shown graphically in Fig. 8.

The weather conditions were not so favorable to rapid curing as for the previous series. Rain threatened during the afternoon of August 22 and a light rain fell during the early morning hours of August 23. The swath cured hay had 53 per cent moisture in the late afternoon of August 22 and 63 per cent at 8 o'clock the next morning. The drying of the hay from this point on corresponded favorably with the series of July 7 and 8 although the lower temperatures and higher humidity prevailing throughout the period made the curing process much slower. The swath cured hay dried faster and reached 30 per cent moisture three hours ahead of that cured in the windrow. The delay in curing that results from cocking hay is well illustrated in this series. The hay curing in the small cocks was fully two days behind the swath cured hay in reaching 40 per cent moisture. The medium cocks cured at a much slower rate than the small cocks, having lost only 20 per cent of their moisture in four days.

Table VIII.

The percentage of moisture in alfalfa at stated intervals as
the rapidity with which the hay gave up its moisture when windro
iately after cutting, as compared with complete swath curing and
ing immediately. Series of August 22, 1927.

Month	Day	Hour	Windrowed Immediately		Swath Cured Completely		Hay Cocked		
							Small Cocks		M
			Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent	We Po
August	22	8			18.2	69.20			
		10	15.6	66.29	16.3	66.29			
		12	14.4	63.50	14.7	62.50	29.4	65.0	118
		2	13.6	61.32	12.8	57.0	29.0	64.41	116
		4	12.4	57.5	11.7	53.0	27.2	62.06	113
		6	12.0	56.50	11.5	52.0	26.8	61.5	110
August	23	8	14.1	62.77	14.8	62.77	27.9	63.0	111
		10	13.2	60.0	12.8	57.0	26.1	60.5	108
		12	12.0	56.0	10.8	48.9	25.0	58.7	106
		2	10.8	51.5	10.0	44.9	24.0	57.0	103
		4	10.0	47.5	9.4	41.5	22.9	55.0	100
		6	9.2	43.0	8.8	37.5	22.0	53.0	98
August	24	8	9.4	44.0	9.0	39.0	22.2	53.5	98
		10	9.2	43.0	8.9	38.09	21.1	51.0	95
		12	8.5	38.0	8.0	31.5	20.6	50.0	93
		2	8.0	34.0	7.6	27.5	20.1	48.7	91
		4	7.5	30.0	7.3	24.0	19.7	47.61	91
		6	7.2	26.5	7.0	21.0	19.5	47.0	88
August	25	8	7.2	26.5	7.0	21.0	19.7	47.5	88
		10	7.1	25.5	6.8	19.5	18.9	45.5	87
		12	7.0	24.5	6.8	18.5	18.3	43.5	85
		2	6.9	23.5	6.7	18.0	17.9	42.5	83
		4	6.8	23.5	6.7	17.76	17.6	41.2	82
		6							

Table VIII.

;age of moisture in alfalfa at stated intervals as indicating
rith which the hay gave up its moisture when windrowed immed-
:utting, as compared with complete swath curing and with cock-
Ly. Series of August 22, 1927.

Windrowed Immediately		Swath Cured Completely		Hay Cocked at Once			
				Small Cocks		Medium Cocks	
Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent
		18.2	69.20				
15.6	66.29	16.3	66.29				
14.4	63.50	14.7	62.50	29.4	65.0	118.2	65.0
13.6	61.32	12.8	57.0	29.0	64.41	116.2	64.40
12.4	57.5	11.7	53.0	27.2	62.06	113.5	63.55
12.0	56.50	11.5	52.0	26.8	61.5	110.3	62.5
14.1	62.77	14.8	62.77	27.9	63.0	111.8	63.0
13.2	60.0	12.8	57.0	26.1	60.5	108.9	62.0
12.0	56.0	10.8	48.9	25.0	58.7	106.1	61.0
10.8	51.5	10.0	44.9	24.0	57.0	103.4	60.0
10.0	47.5	9.4	41.5	22.9	55.0	100.9	59.0
9.2	43.0	8.8	37.5	22.0	53.0	98.5	58.0
9.4	44.0	9.0	39.0	22.2	53.5	98.5	58.0
9.2	43.0	8.9	38.09	21.1	51.0	95.1	56.5
8.5	38.0	8.0	31.5	20.6	50.0	93.0	55.5
8.0	34.0	7.6	27.5	20.1	48.7	91.9	55.0
7.5	30.0	7.3	24.0	19.7	47.61	91.4	54.64
7.2	26.5	7.0	21.0	19.5	47.0	88.9	53.5
7.2	26.5	7.0	21.0	19.7	47.5	88.0	53.0
7.1	25.5	6.8	19.5	18.9	45.5	87.1	52.5
7.0	24.5	6.8	18.5	18.3	43.5	85.3	51.5
6.9	23.5	6.7	18.0	17.9	42.5	83.6	50.5
6.8	23.5	6.7	17.76	17.6	41.2	82.7	50.0

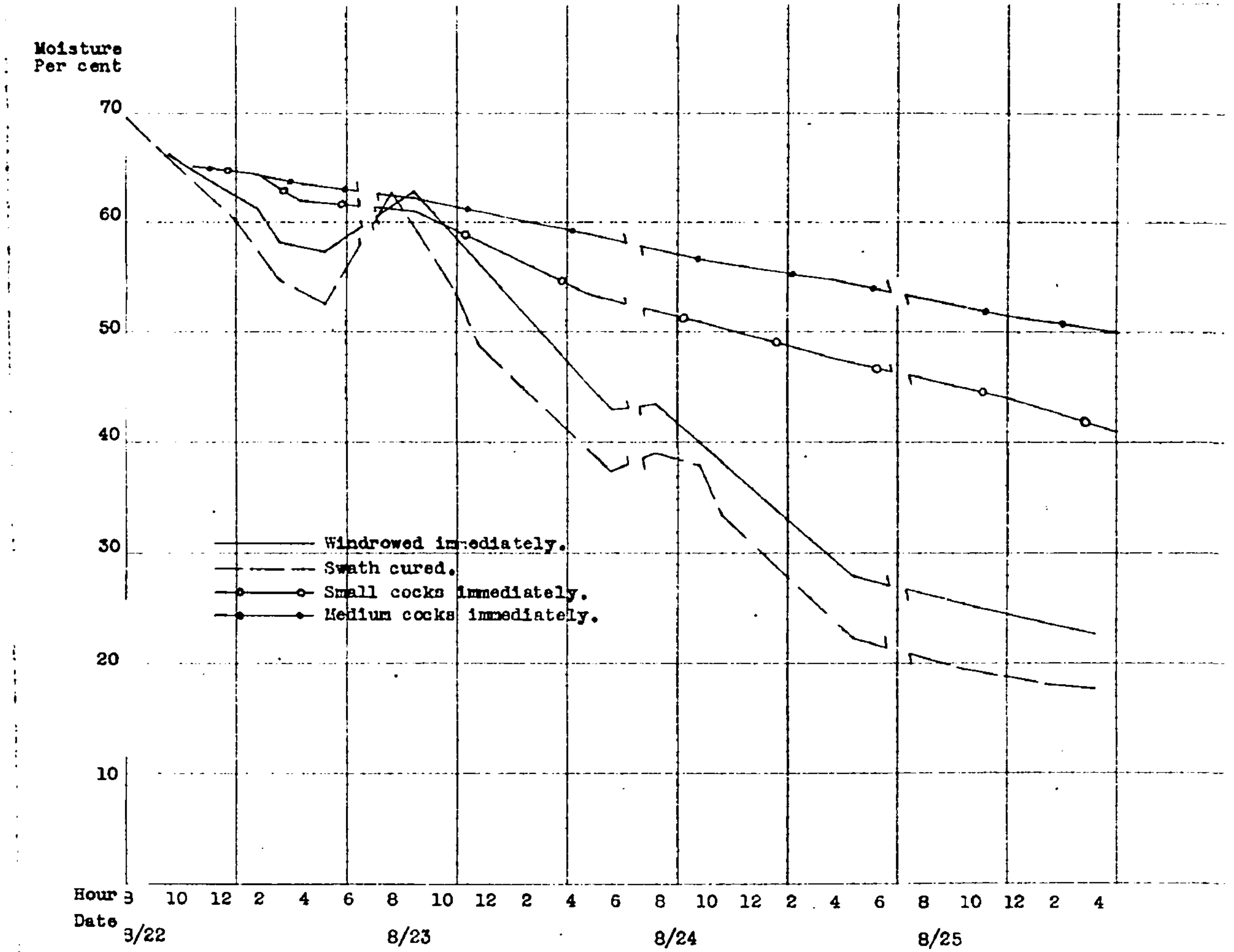

Fig. 8. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when windrowed immediately after cutting, as compared with complete swath curing and with cocking immediately. Series of August 22.

Series of August 23. Clear weather prevailed throughout with high relative humidity in the early part of the experiment. The hay for this test was similar to that used on August 22. The hay was cut between 1:30 and 2:30 P. M. The results of this experiment are given in Table IX and the moisture content of the hay for each method is shown graphically in Fig. 9.

The hay used for the series cut on August 23 was rather heavy succulent alfalfa. The swath cured hay reached 30 per cent in approximately 14 hours, then dried rather more slowly during the following 18 hours. The windrow cured hay did not dry to 30 per cent moisture until 32 hours of curing time had elapsed. This wide difference in the relative speed of the swath and windrow cured hay arose from the fact that the swath cured hay had reached 30 per cent before the check in its rate of drying occurred on August 25, while the windrow cured hay did not reach 30 per cent until afterward. The reason for this check in the rate of the loss in moisture on August 25 is not clear. The relative humidity was slightly higher than on August 24 but the temperature was likewise higher.

During this period of curing cocked hay did not dry out satisfactorily. The small cocks had lost only

Table IX.

The percentage of moisture in alfalfa at stated intervals as i
the rapidity with which the hay gave up its moisture when windrowe
iately after cutting, as compared with complete swath curing and w
ing immediately. Series of August 23, 1927.

Month	Day	Hour	Windrowed Immediately Weight Pounds	Windrowed Immediately Moisture Per cent	Swath Cured Completely Weight Pounds	Swath Cured Completely Moisture Per cent	Hay Cocked Small Cocks Weight Pounds	Hay Cocked Small Cocks Moisture Per cent	M We Pc
August	23	12							
		2	15.5	68.36	13.5	68.36	35.2	68.36	11
		4	14.4	66.0	11.0	61.18	34.3	67.5	11
		6	13.2	63.0	9.9	57.0	33.8	67.0	11
August	24	8	13.2	63.0	9.9	51.0	32.2	65.5	10
		10	12.2	60.0	9.3	54.09	31.4	64.5	10
		12	11.0	55.5	7.6	44.0	30.5	63.5	10
		2	9.8	50.0	6.6	35.5	29.3	62.0	10
		4	8.9	45.0	6.0	28.5	28.5	60.91	9
		6	8.6	43.0	5.4	20.5	27.9	60.0	9
August	25	8	8.6	43.0	5.4	20.5	27.2	59.0	9
		10	8.4	41.5	5.3	20.0	26.5	58.0	9
		12	8.2	40.0	5.3	19.0	25.9	57.0	9
		2	7.9	38.0	5.2	18.5	25.3	56.0	8
		4	7.7	36.0	5.2	18.0	24.5	54.5	8
		6	7.4	34.0	5.2	17.5	24.0	53.5	8
August	26	8	7.4	34.0	5.2	17.5	23.7	53.0	8
		10	7.1	30.9	5.1	16.27	23.5	52.60	8
		12	6.9	29.0	4.9	13.0	23.0	51.5	8
		2	6.8	27.5	4.7	8.5	22.5	50.5	8
		4	6.6	25.76	4.6	7.17	22.0	49.36	8.
		6							

Table IX.

;e of moisture in alfalfa at stated intervals as indicating
;h which the hay gave up its moisture when windrowed immed-
;ting, as compared with complete swath curing and with cock-
Series of August 23, 1927.

Windrowed Immediately		Swath Cured Completely		Hay Cocked at Once			
				Small Cocks		Medium Cocks	
Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent
15.5	68.36	13.5	68.36	35.2	68.36	115.2	68.36
14.4	66.0	11.0	61.18	34.3	67.5	113.9	68.0
13.2	63.0	9.9	57.0	33.8	67.0	112.1	67.5
13.2	63.0	9.9	51.0	32.2	65.5	108.8	66.5
12.2	60.0	9.3	54.09	31.4	64.5	104.1	65.0
11.0	55.5	7.6	44.0	30.5	63.5	102.7	64.5
9.8	50.0	6.6	35.5	29.3	62.0	101.3	64.0
8.9	45.0	6.0	28.5	28.5	60.91	99.2	63.26
8.6	43.0	5.4	20.5	27.9	60.0	95.9	62.0
8.6	43.0	5.4	20.5	27.2	59.0	94.7	61.5
8.4	41.5	5.3	20.0	26.5	58.0	92.3	60.5
8.2	40.0	5.3	19.0	25.9	57.0	91.1	60.0
7.9	38.0	5.2	18.5	25.3	56.0	88.9	59.0
7.7	36.0	5.2	18.0	24.5	54.5	87.7	58.5
7.4	34.0	5.2	17.5	24.0	53.5	86.8	58.0
7.4	34.0	5.2	17.5	23.7	53.0	85.8	57.5
7.1	30.9	5.1	16.27	23.5	52.60	85.2	57.22
6.9	29.0	4.9	13.0	23.0	51.5	84.8	57.0
6.8	27.5	4.7	8.5	22.5	50.5	82.2	56.0
6.6	25.76	4.6	7.17	22.0	49.36	81.5	55.28

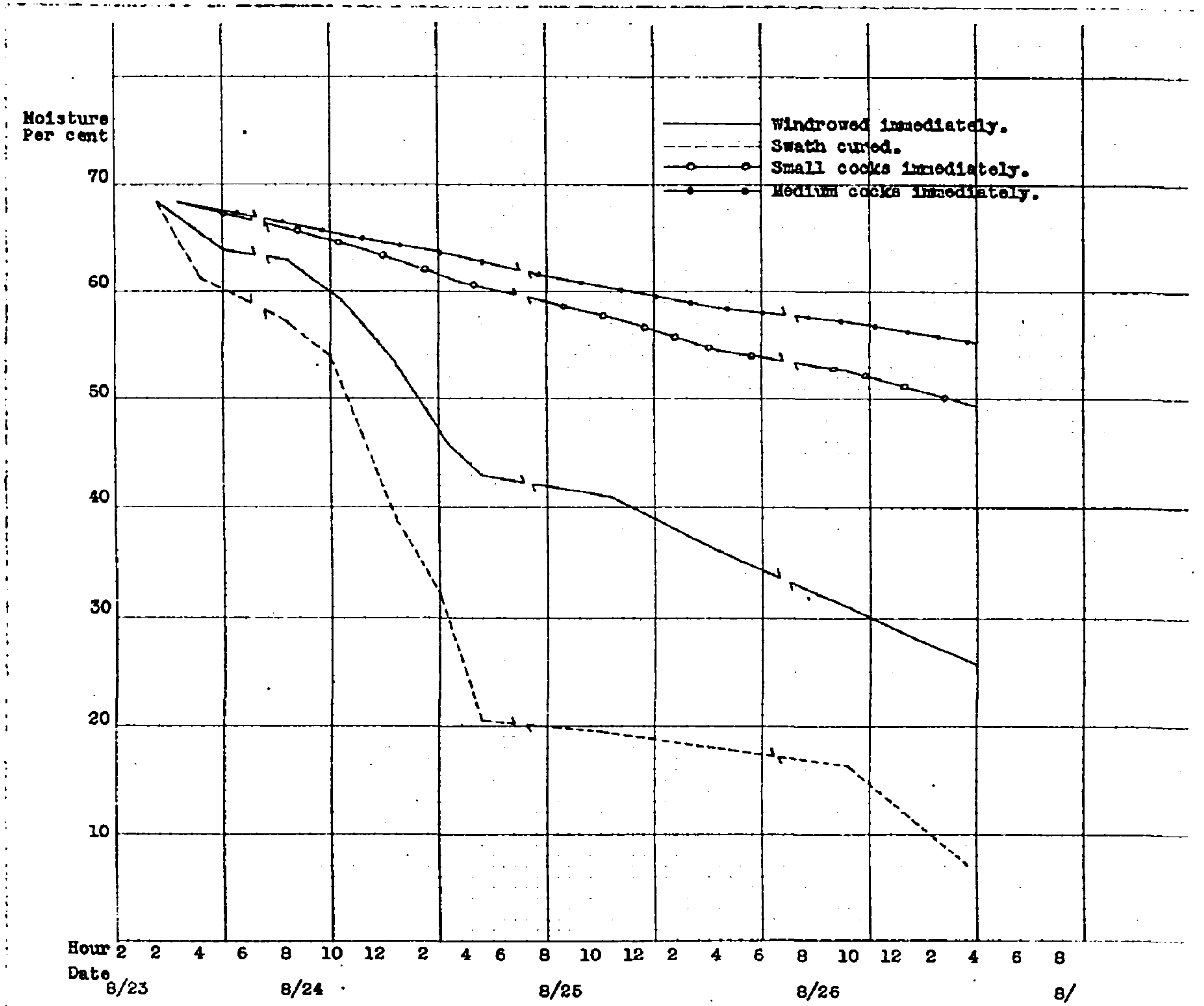

Fig. 9. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when windrowed immediately after cutting, as compared with complete swath curing and with cooking immediately. Series of August 23.

18 per cent moisture while the medium cocks had lost but 13 per cent at the end of the fourth day of curing.

The experiments on the relative rate of curing in the windrow, swath, and cock, show clearly that under swath curing the hay cures out much faster than in the windrow or cock. The time that elapsed between the cutting and the point in the curing where the hay has 30 per cent moisture is indicated for each method of curing in the following figures. The rate of curing by the different methods for the four series may be summed up as follows:

Method of Curing	Elapsed Time in Drying Hours in the Series of:				
	July 7	July 8	Aug 22	Aug 23	Average
Windrowed immediately	18	12	30	32	23
Swath Cured entirely	16	9	29	14	17.0
Small cocks immediately	24	20	76	81	51
Medium cocks immediately	40	--	117	118	91

The actual difference in hours varies with the prevailing relative humidity and temperature, and with the mass of hay being handled.

The recommendation of windrowing at once cannot be made from the standpoint of hastening the curing of hay. In the work of Kiesselbach and Anderson a summarization from their experiments indicates 27 hours elapsed time for swath curing to reach 30 per cent and 65 hours for windrow curing, but when calculated on the hours from 7 A. M. to 7 P. M. the swath curing required 15 hours and the windrow curing 35 hours. In general this would indicate that windrows cure faster in proportion here than in Nebraska.

In view of this evidence, the theory that windrowing immediately hastens curing would appear to be incorrect. The method may be desirable on other grounds, but the claim that the windrowing would keep the leaves alive and therefore would aid in withdrawing moisture from the stems, with the result of hastening the curing of the hay, is not justified under central Iowa conditions.

There is a possibility that windrowing immediately may be advantageous in actually speeding up curing with extremely heavy windrows or with heavy stemmed types of hay. It would appear that for speed of drying the greater advantage of swath over windrow curing occurs with the most rapid drying conditions and with the finer stemmed alfalfa hays. The difference between swath and windrow curing was the least during the one period with extra heavy hay and slow drying conditions.

B. The Rate of Curing Hay in the Windrow Compared with Partial Curing in the Swath, Followed by Windrow Curing.

The four series described as to weather and hay used in experiment A. included a comparison of complete windrow curing with partial swath curing followed by windrowing. The four methods tested in this experiment include hay cured completely in the windrow in comparison with hay cured one-fourth, one-half and three-fourths in the swath prior to the windrowing. Two swaths 100 yards long were windrowed as soon as cut; two when weighings indicated that the hay in the swath was one-fourth cured; two when one-half, and the other two when the hay was three-fourths cured. For each method of curing, the hay for the different areas was weighed as soon as it was windrowed.

The weights and moisture percentages recorded in Tables X to XIII, inclusive, are averages for five areas in the July 7 series and three areas in each of the others.

In the series of July 7 a study of Table X and Figure 10 shows that hay which was allowed to cure one-half and three-fourths in the swath prior to windrowing gave up its moisture more rapidly than hay windrowed at once.

Table X.

The percentage of moisture in alfalfa at stated intervals as indicating rapidity with which the hay gave up its moisture when windrowed immediately after cutting, as compared with hay partially swath cured before windrowing. Series of July 7, 1927.

			Windrowed Immediately		One-fourth Swath Cured then Windrowed		One-half Swath Cured then Windrowed		Three-fourths Swath Cured then Windrowed	
Month	Day	Hour	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent
July	7	8	29.9	67.0						
		10	27.0	63.5						
		12	24.9	60.5						
		2	23.5	58.0	30.7	57.5				
		4	21.5	54.0	27.2	52.0	20.6	52.5		
		6	19.7	50.0	25.3	48.5	19.2	49.0		
July	8	8	18.3	46.0	24.2	46.0	18.3	46.5		
		10	17.2	42.5	22.9	43.0	15.8	37.5	14.2	41.5
		12	15.7	37.0	20.9	37.5	14.2	30.5	11.5	27.5
		2	13.9	28.99	19.3	32.5	12.8	23.5	10.5	21.0
		4	12.6	21.6	18.5	29.5	12.7	22.5	10.3	19.0
					17.4	25.0	12.2	19.5	10.3	19.0
July	9	8			16.7	22.0	11.8	16.5	10.3	19.0
		9			16.6	21.5	11.7	15.5	10.3	19.0

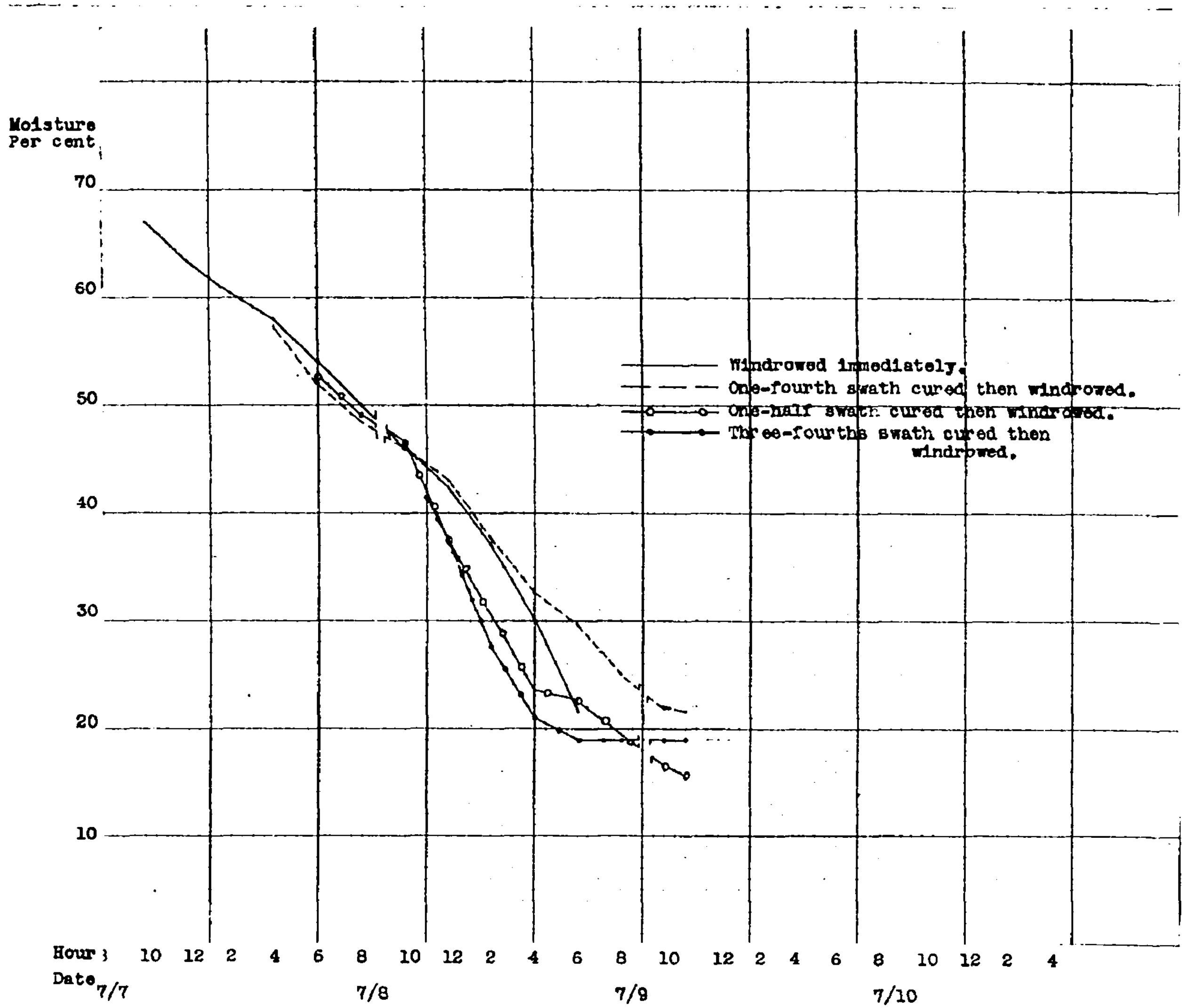

Fig. 10. The percentage of moisture in alfalfa at stated intervals as indicating rapidity with which the hay gave up its moisture when windrowed immediately after cutting, as compared with hay partially swath cured before windrowing. Series of July 7, 1927.

Table XI.

The percentage of moisture in alfalfa at stated intervals as indicating rapidity with which the hay gave up its moisture when windrowed immediately after cutting as compared with hay partially swath cured before windrowing. Series of July 8, 1927.

			Windrowed Immediately		One-fourth Swath Cured then Windrowed		One-half Swath Cured then Windrowed		Three-fourths Swath Cured then Windrowed	
Month	Day	Hour	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent
July	8	8								
		10	31.3	60.5						
		12	28.3	56.32	21.8	53.5				
		2	24.9	50.5	19.1	47.0				
		4	22.2	44.5	17.5	42.06	18.3	36.11		
		6	20.6	40.0	16.5	38.55	17.3	32.43	15.5	34.02
July	9	8	19.3	35.96	15.1	32.85	15.6	25.06	14.4	28.96
		10	17.5	29.37	14.3	29.09	15.0	22.07	13.6	24.78
		12	16.8	26.50	13.8	26.52	14.5	19.38	13.0	21.31
		2	16.6	25.75	12.9	21.5	14.4	19.0	12.9	20.5
		4								

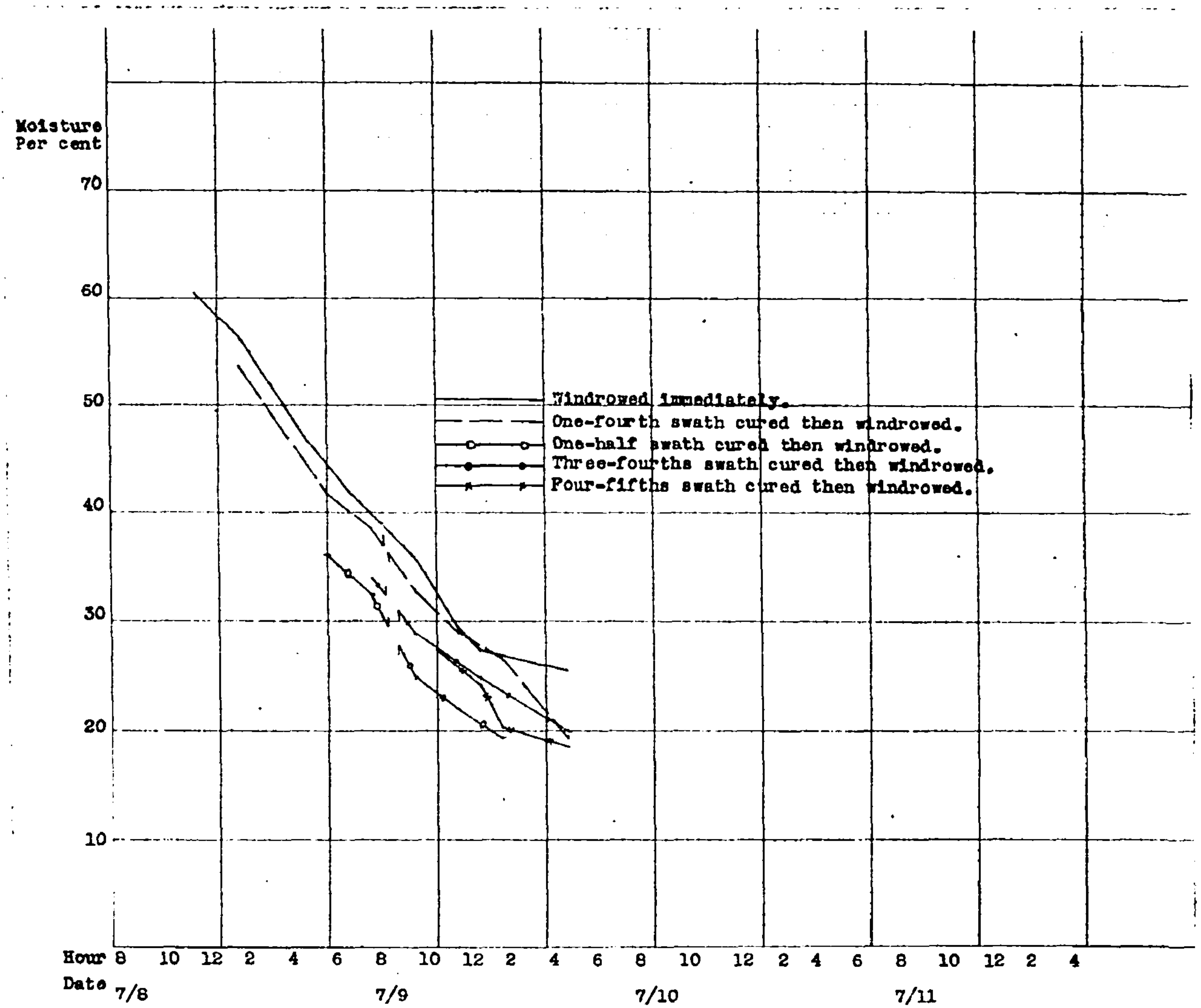

Fig. 11. The percentage of moisture in alfalfa at stated intervals as indicating rapidity with which the hay gave up its moisture when windrowed immediately after cutting as compared with hay partially swath cured before windrowing. Series of July 8, 1927.

Table XII.

The percentage of moisture in alfalfa at stated interval
cating rapidity with which the hay gave up its moisture whe
ed immediately after cutting, as compared with hay partiall
cured before windrowing. Series of August 22, 1927.

Month	Day	Hour	Windrowed Immediately: Weight Pounds	Windrowed Immediately: Moisture Per cent	One-fourth Swath Cured then Windrowed: Weight Pounds	One-fourth Swath Cured then Windrowed: Moisture Per cent	One-hal then: Weight Pounds
August	22	8					
		10	15.6	66.29	21.1	64.69	
		12	14.4	63.50	18.0	62.0	
		2	13.6	61.32	17.3	56.82	
		4	12.4	57.50	16.0	53.27	
		6	12.0	56.50	15.4	51.5	
August	23	8	14.1	62.77	19.7	62.0	
		10	13.2	60.0	17.2	56.57	
		12	12.0	56.0	14.5	48.5	10.3
		2	10.8	51.5	13.7	45.5	10.1
		4	10.0	47.5	13.1	43.0	9.7
		6	9.2	43.0	12.5	40.0	9.3
August	24	8	9.4	44.0	12.6	40.5	9.3
		10	9.2	43.0	12.5	40.0	8.7
		12	8.5	38.0	11.4	34.5	8.3
		2	8.0	34.0	10.7	30.5	7.9
		4	7.5	30.0	10.1	26.5	7.6
		6	7.2	26.5	9.6	22.5	7.5
August	25	8	7.2	26.5	9.6	22.5	7.4
		10	7.1	25.5	9.4	20.5	7.4
		12	7.0	24.5	9.2	19.0	7.4
		2	6.9	23.5	9.1	18.0	7.4
		4	6.8	22.65	9.0	17.0	7.3
		6					

Table XII.

centage of moisture in alfalfa at stated intervals as indi-
idity with which the hay gave up its moisture when windrow-
tely after cutting, as compared with hay partially swath
re windrowing. Series of August 22, 1927.

Windrowed Immediately		One-fourth Swath Cured then Windrowed		One-half Swath Cured then Windrowed	
Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent
15.6	66.29	21.1	64.69		
14.4	63.50	18.0	62.0		
13.6	61.32	17.3	56.82		
12.4	57.50	16.0	53.27		
12.0	56.50	15.4	51.5		
14.1	62.77	19.7	62.0		
13.2	60.0	17.2	56.57		
12.0	56.0	14.5	48.5	10.3	46.20
10.8	51.5	13.7	45.5	10.1	45.0
10.0	47.5	13.1	43.0	9.7	43.0
9.2	43.0	12.5	40.0	9.3	40.5
9.4	44.0	12.6	40.5	9.3	40.5
9.2	43.0	12.5	40.0	8.7	36.5
8.5	38.0	11.4	34.5	8.3	33.0
8.0	34.0	10.7	30.5	7.9	30.0
7.5	30.0	10.1	26.5	7.6	27.0
7.2	26.5	9.6	22.5	7.5	26.0
7.2	26.5	9.6	22.5	7.4	25.5
7.1	25.5	9.4	20.5	7.4	25.5
7.0	24.5	9.2	19.0	7.4	25.5
6.9	23.5	9.1	18.0	7.4	25.0
6.8	22.65	9.0	17.0	7.3	24.5

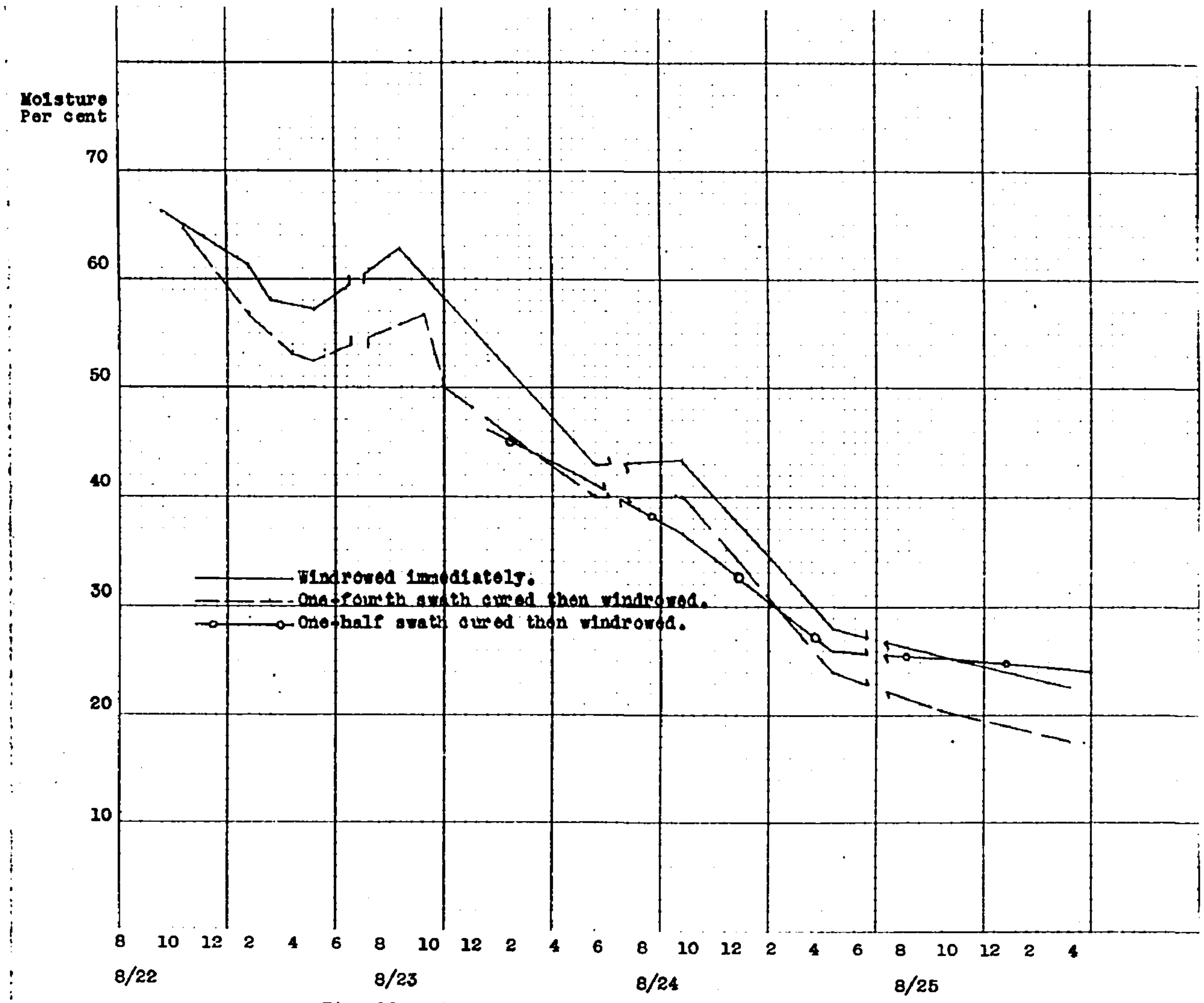

Fig. 12. The percentage of moisture in alfalfa at stated intervals as indicating rapidity with which the hay gave up its moisture when windrowed immediately after cutting, as compared with hay partially swath cured before windrowing. Series of August 22, 1927.

Table XIII.

The percentage of moisture in alfalfa at stated inte
rapidity with which the hay gave up its moisture when w
ly after cutting as compared with hay partially swath c
ing. Series of August 23, 1927.

Month	Day	Hour	Windrowed Immediately Weight Pounds	Windrowed Immediately Moisture Per cent	One-fourth Swath Cured then Windrowed Weight Pounds	One-fourth Swath Cured then Windrowed Moisture Per cent	One-half S ed then W Weight Pounds
August	23	12					
		2	15.5	68.36			
		4	14.4	66.0			
		6	13.2	63.0			
August	24	8	13.2	63.0			
		10	12.3	60.0	11.5	53.82	
		12	11.0	55.5	11.2	52.5	
		2	9.8	50.0	10.0	47.0	8.0
		4	8.9	45.0	8.9	40.5	7.4
		6	8.6	43.0	8.2	35.0	7.0
August	25	8	8.6	43.0	8.2	35.0	7.0
		10	8.4	41.5	8.0	33.5	6.8
		12	8.2	40.0	7.8	31.5	6.7
		2	7.9	38.0	7.5	29.5	6.5
		4	7.7	36.0	7.3	27.5	6.4
		6	7.4	34.0	7.2	26.0	6.3
August	26	8	7.4	34.0	7.2	26.0	6.3
		10	7.1	30.9	7.0	24.5	6.2
		12	6.9	29.0	6.8	22.0	6.0
		2	6.8	27.5	6.6	19.5	5.7
		4	6.6	25.75	6.3	15.71	5.6
							5.5

Table XIII.

e of moisture in alfalfa at stated intervals as indicating
ich the hay gave up its moisture when windrowed immediate-
as compared with hay partially swath cured before windrow-
August 23, 1927.

wed tely	One-fourth Swath Cured then Windrowed		One-half Swath Cured then Windrowed		Three-fourths Swath Cured then Windrowed	
isture r cent	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent	Weight Pounds	Moisture Per cent
68.36						
66.0						
63.0						
63.0						
60.0	11.5	53.82				
55.5	11.2	52.5				
50.0	10.0	47.0	8.0	39.0		
45.0	8.9	40.5	7.4	34.0		
43.0	8.2	35.0	7.0	30.0		
43.0	8.2	35.0	7.0	30.0		
41.5	8.0	33.5	6.8	28.5	5.3	22
40.0	7.8	31.5	6.7	27.0	5.3	21.5
38.0	7.5	29.5	6.5	25.0	5.1	19.0
36.0	7.3	27.5	6.4	24.0	5.0	17.0
34.0	7.2	26.0	6.3	23.0	4.9	15.0
34.0	7.2	26.0	6.3	23.0	4.8	14.5
30.9	7.0	24.5	6.2	21.0	4.7	13.0
29.0	6.8	22.0	6.0	18.5	4.7	12.0
27.5	6.6	19.5	5.7	15.0	4.7	11.5
25.75	6.3	15.71	5.6	12.5	4.6	10.2
			5.5	11.48		

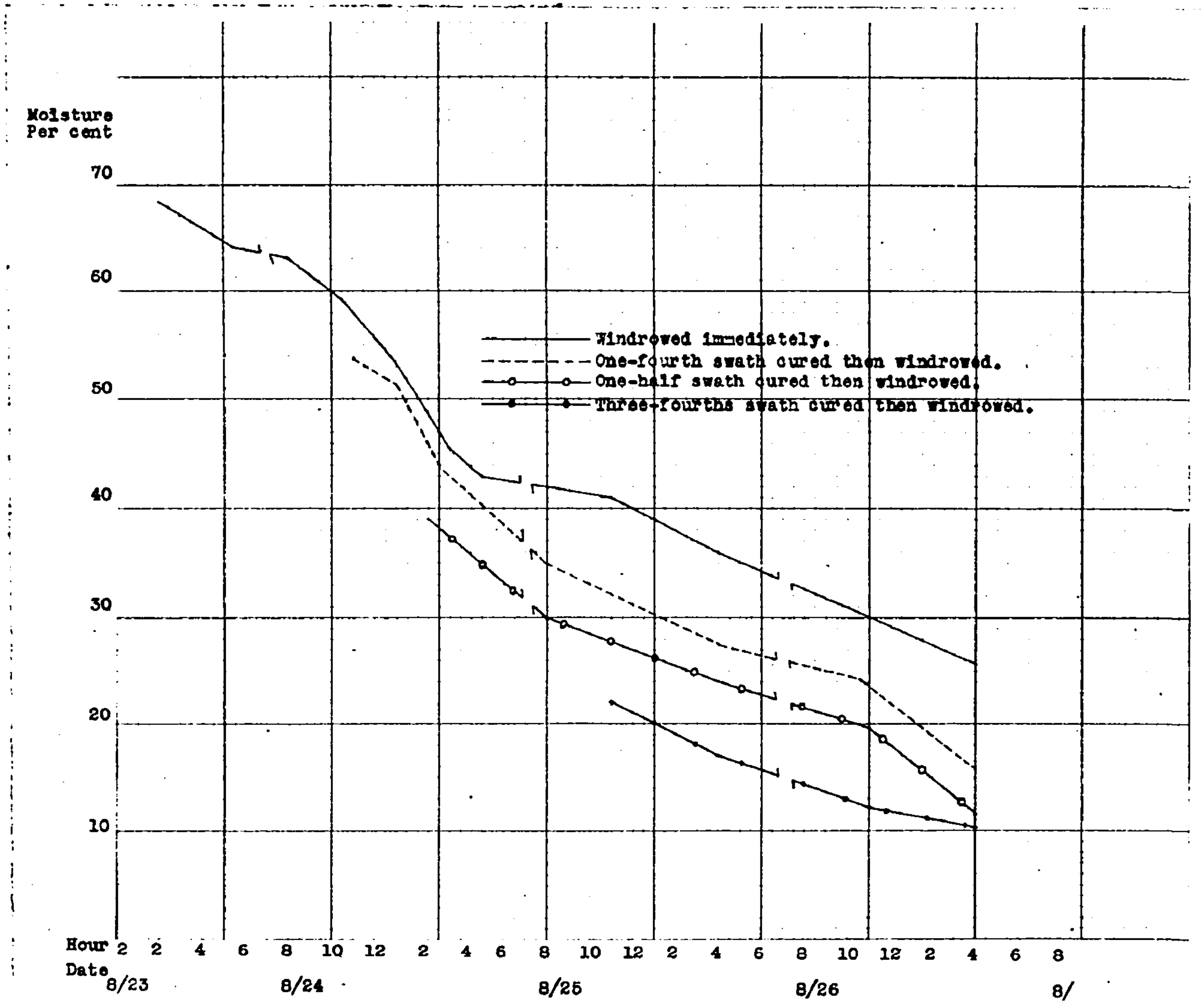

Fig. 13. The percentage of moisture in alfalfa at stated intervals as indicating rapidity with which the hay gave up its moisture when windrowed immediately after cutting as compared with hay partially swath cured before windrowing. Series of August 23, 1927.

The one-half swath cured hay was reduced to 30 per cent moisture three hours earlier than the hay windrowed at once and one-half hour later than hay three-fourths cured in the swath prior to windrowing. For some unknown reason the hay one-fourth cured then windrowed did not dry as fast as that windrowed at once, especially during the second day of the curing. The hay windrowed immediately was dried to 30 per cent moisture two hours earlier than the hay one-fourth swath cured then windrowed.

In the July 8 series, a study of Table XI and Figure 11 indicates that hay windrowed at once lost its moisture more slowly than any other method. The hay cured one-half in the swath then windrowed, dried most rapidly reaching 30 per cent moisture three and one-half hours earlier than the hay windrowed at once; three hours earlier than hay one-fourth swath cured prior to windrowing and one hour sooner than hay three-fourths swath cured followed by windrowing. At the end of the test, one-fourth swath cured hay contained 19 per cent moisture while hay windrowed immediately contained 25 per cent. The one-half swath cured hay was reduced to 30 per cent moisture in 9 hours after cutting while all of the others did not reach this degree of drying until the next day.

In the series of August 22, a study of Table XII and Figure 12 indicates that the one-fourth swath cured hay cured out most rapidly. The one-fourth swath cured hay had dried to 52 per cent moisture in 8 hours while hay in the windrow had 57 per cent. The advantage in drying of the one-fourth swath cured hay was maintained throughout the experiment and the hay was dried to 30 per cent at the same time as hay one-half swath cured and two hours prior to the hay windrowed at once. The hay curing in the swath had 62 per cent moisture early in the morning of the second day. This meant that the hay one-fourth cured in the swath gained 11 per cent in moisture on account of the light rain while the windrow curing hay gained but 6 per cent.

The series of August 23 was the most regular of the four as will be observed from a study of Table XIII and Figure 13. The hay windrowed immediately cured out most slowly, followed by the one-fourth swath cured, then the one-half, while the hay three-fourths swath cured was first. The moisture content of the hay curing in the swath in this series was so much drier than was expected that the time for windrowing the three-fourths cured hay was overlooked. At the time the three-fourths swath cured hay was windrowed, it contained but 22 per cent moisture, while the windrow curing hay had 41 per cent at the same hour. The time required for drying the hay to 30 per cent moisture under the various systems was, for the windrowed immediately, 32 hours; one-fourth swath cured, 24 hours, and the one-half swath cured, 16 hours. The three-fourths swath cured is estimated to have been down to 30 per cent of moisture in about 12 hours.

The effect of partial swath curing then windrowing on the rate of curing of the hay is shown in the following summary of the hours of elapsed time from the time of cutting until the hay has 30 per cent moisture.

Method of curing	Elapsed Time in Hours in the Series of --				
	July 7	July 8	Aug 22	Aug 23	Average
Windrowed immediately	18	12	30	32	23.0
Swath cured completely	16	9	29	14	17.0
One-fourth swath cured then windrowed	20	12	28	24	21.0
One-half swath cured then windrowed	16	9	28	16	17.0
Three-fourths swath cured then windrowed	15	9	--	12	14.0

From the standpoint of time, the methods of curing ranked in approximately the same order in each series. Swath curing was most rapid, followed by the $\frac{3}{4}$, the $\frac{1}{2}$ and the $\frac{1}{4}$ swath cured, respectively, and last the hay that was windrowed immediately.

C. A Comparison of the Rate of Curing of Alfalfa Hay in the Windrow and in the Cock when the Cocking is done after Partial Swath Curing.

In this experiment full windrow curing is compared with cocking immediately in small and medium sized cocks; and with hay cured one-fourth, one-half and three-fourths, respectively in the swath then cocked in small and medium sized cocks. The general procedure consisted of weighing areas of the swath at intervals until the one-fourth stage of curing was reached when four swaths were windrowed and cocked. The same process was repeated when the swath curing hay had reached one-half, and again when three-fourths cured.

As under A, four series of comparisons were made. The hay and weather conditions were as described for identical dates under A. The weights and moisture percentages recorded in Tables XIV to XVII inclusive are averages for the three weighings.

From Table XIV,(Figure 14)it will be seen that for the July series hay cured in the windrow much more quickly than in either small or medium sized cocks even when the hay was allowed to partly cure in the swath before being placed in the cock. The curing was rather regular and consistent, hay one-fourth swath cured and

Table XIV.

The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when windrowed immediately after cutting, as compared with hay cocked immediately and with hay partly swath cured before cocking. Series of July 7, 1927.

Month	Day	Hour	Windrowed Immediately		Cocked Immediately		One-fourth Swath Cured then Cocked		One-half Swath Cured then Cocked	
			Weight	Moisture	Small Cocks Moisture	Medium Cocks Moisture	Small Cocks Moisture	Medium Cocks Moisture	Small Cocks Moisture	Medium Cocks Moisture
			Pounds	Per cent	Per cent	Per cent	Per cent	Percent	Per cent	Per cent
July	7	8	29.9	67.00	67.0	67.0				
		10	27.0	63.50	66.0	66.0				
		12	24.9	60.5	62.5	64.0				
		2	23.5	58.0	59.5	62.0	56.5	56.5		
		4	21.5	54.0	57.0	59.5	51.5	54.0	51.5	51.5
		6	19.7	50.0	54.5	59.0	49.5	53.0	50	50.0
July	8	8	18.3	46.07	53.5	57.5	49.5	52.0	49.5	49.0
		10	17.2	42.5	51.5	56.5	45.0	49.5	46.0	46.5
		12	15.7	37.0	48.0	54.5	39.5	47.0	39.5	43.5
		2	13.9	28.9	43.5	52.5	38.0	46.0	36.0	41.5
		4	12.6	21.6	39.5	49.5	35.0	45.0	32.5	39.0
		6			35.5	47.5	31.5	43.0	30.0	36.0
July	9	8			32.0	45.0	30.0	40.5	27.0	33.5
		10			29.5	44.5	29.0	39.5	25.5	32.0

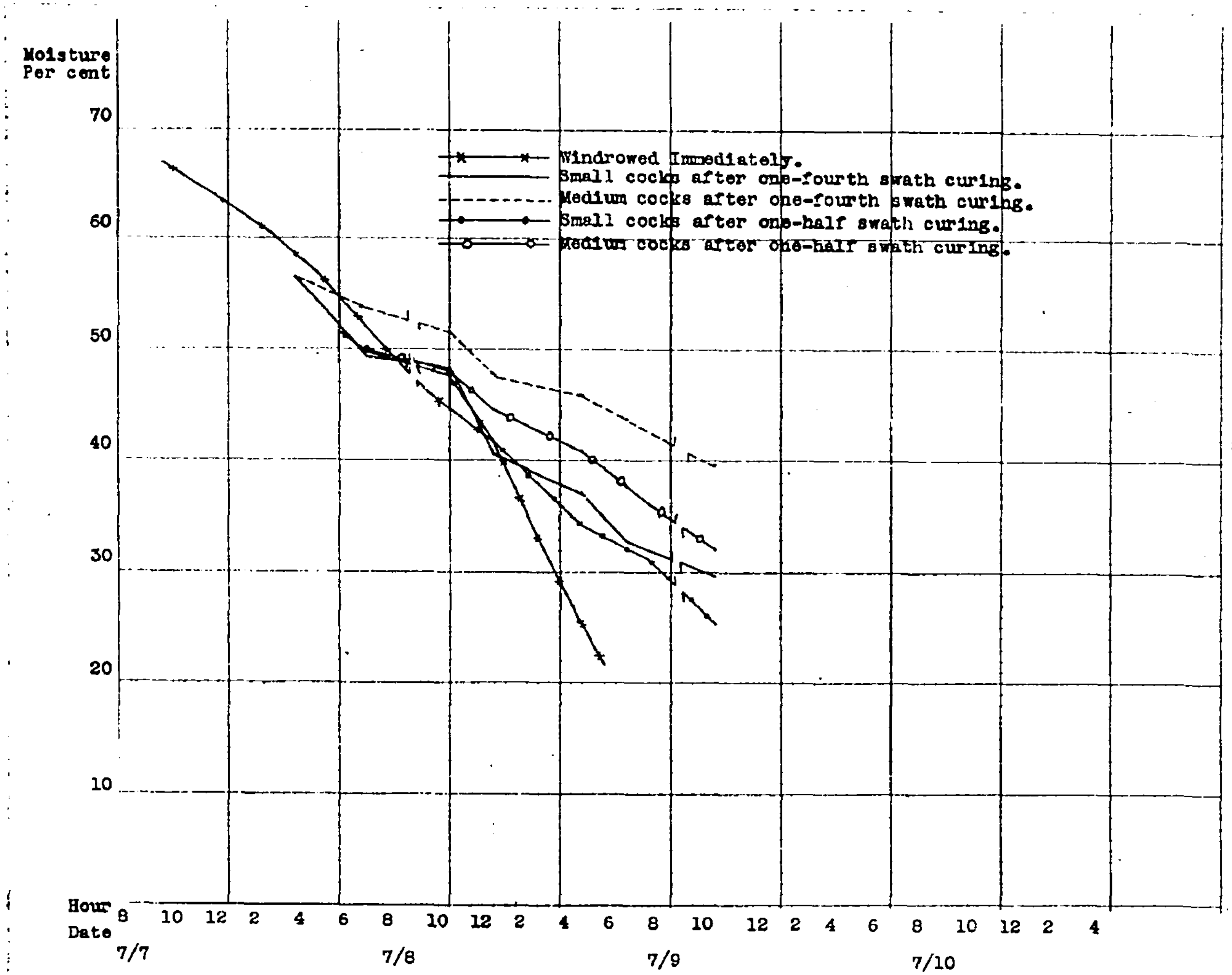

Fig. 14. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when windrowed immediately after cutting, as compared with hay cocked immediately and with hay partly swath cured before cocking. Series of July 7, 1927.

then placed in medium cocks curing in 40 hours, with medium cocks after one-half swath curing in 30 hours, followed by hay one-fourth swath cured and finished in small cocks in 24 hours. Hay put in the windrow immediately after cutting had dried down to 30 per cent moisture at the end of 18 hours while from 24 to 22 hours were required for hay to cure when placed in small cocks after curing one-half and one-fourth in the swath prior to cocking. It is perhaps rather surprising to find hay placed in the windrow curing more rapidly than hay one-half swath cured and then placed in small cocks.

In the series of July 8 (Table XV and Figure 15) the hay placed in small cocks after curing one-fourth in the swath, cured more slowly than that windrowed immediately reaching 30 per cent moisture in 15 hours in the cock and 12 hours in the windrow. Hay cocked in small cocks after one-half swath cured, dried in 10 hours, while hay in medium cocks after one-half swath curing dried in 12 hours, just the same as the windrow curing hay. Hay placed in small cocks after curing one-half in the swath had dried down to 30 per cent in 10 hours, while 12 hours were required for hay in the windrow to reach the same degree of dryness. The rapid swath curing prior to cocking gave the cocked hay an advantage that the

Table XV.

The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when windrowed immediately after cutting, as compared with hay cocked immediately and with hay partly swath cured before cocking. Series of July 8, 1927.

Month	Day	Hour	Windrowed Immediately		Cocked Immediately: Small Cocks	One-fourth Swath Cured then Cocked: Small Cocks	One-half Swath Cured then Cocked	
							Small Cocks	Medium Cocks
			Weight Pounds	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent
July	8	8						
		10	31.3	60.5	59.7			
		12	28.3	56.3	56.77	53.5		
		2	24.9	50.5	52.5	50.5		
		4	22.2	44.5	48.5	48.58	36.11	36.11
		6	20.6	40.0	45.5	44.36	30.83	34.02
July	9	8	19.3	35.9	43.72	39.16	25.00	29.81
		10	17.5	29.4	40.15	35.96	23.00	28.0
		12	16.8	26.5			20.83	25.13
		2	16.6	25.8				

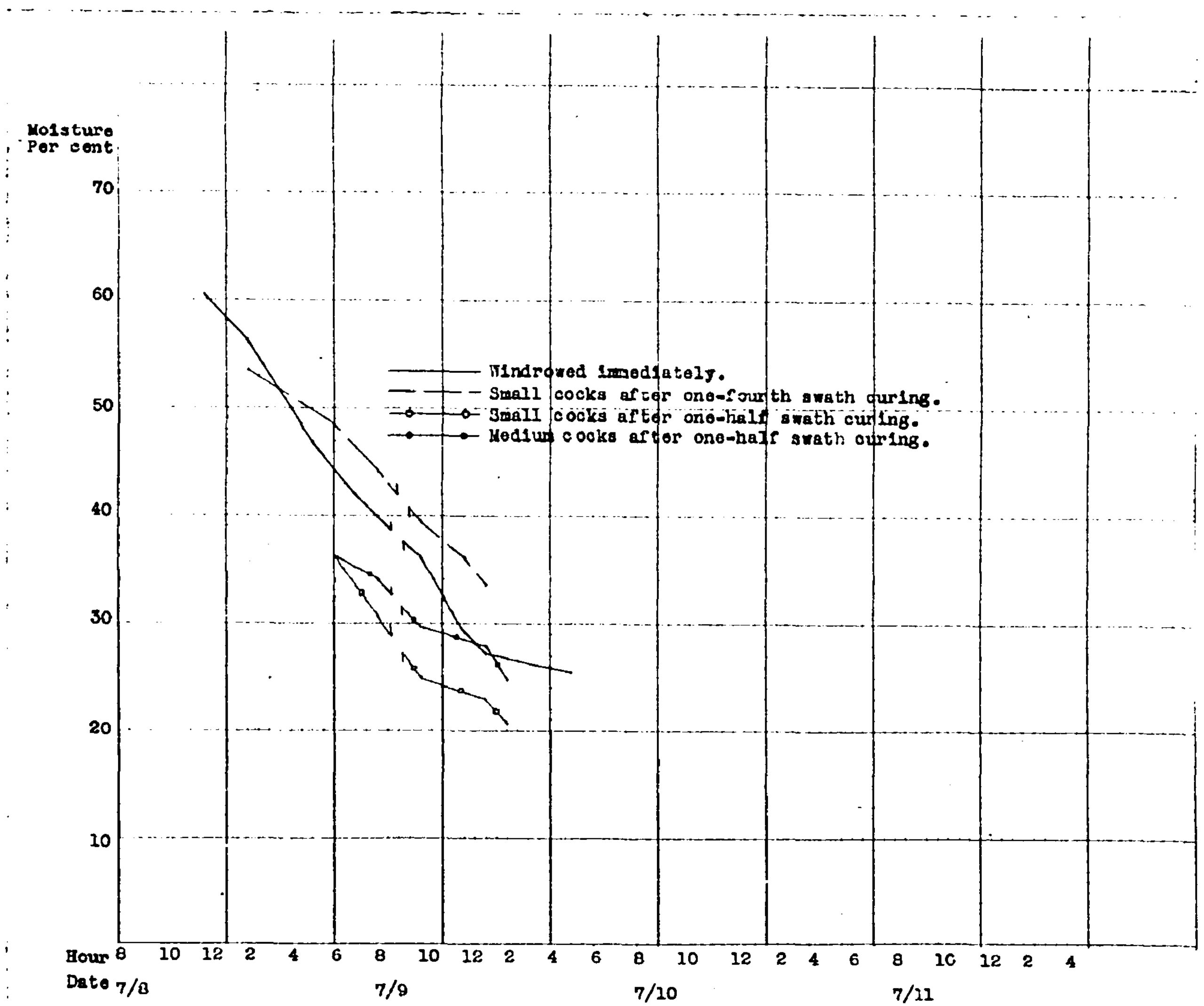

Fig. 15. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when windrowed immediately after cutting, as compared with hay cocked immediately and with hay partly swath cured before cocking. Series of July 8,1927.

windrow cured hay could not overcome, although the windrow curing hay dried more rapidly than the hay in the cock.

In the August 22 series (Table XVI and Figure 16) the loss of moisture for hay placed in the windrow at once, which may be regarded as a standard, performed rather erratically. In general it dried more rapidly than hay placed in cocks either immediately or after they were only one-fourth cured in the swath. Hay allowed to one-half or three-fourths cure in the swath before cocking, cured more rapidly than the hay in the windrow. The longer the hay was in the swath the more rapidly it dried. The hay in all cases dried more rapidly in the small than in the medium cocks. Hay allowed to one-half cure in the swath and then placed in small cocks reached the 30 per cent moisture stage in 28 hours from cutting, while the same hay placed in medium cocks required 36 hours. Hay allowed to three-fourths cure in the swath was below 30 per cent when it was placed in the windrow, while that placed in cocks when only one-fourth cured, or cocked immediately when cut, had from 40 to 50 per cent of moisture at the end of the four days during which the hay was weighed. It will be noted that in all cases the rate of

Table XVI.

The percentage of moisture in alfalfa at stated
the rapidity with which the hay gave up its moistu
iately after cutting, as compared with hay cocked
partly swath cured before cooking. Series of Augu

Month	Day	Hour	Windrowed Immediately Weight Pounds	Windrowed Immediately Moisture Per cent	Cocked Immediately Small Cocks Moisture Per cent	Cocked Immediately Medium Cocks Moisture Per cent	One-fourth Swat Cured then Cock Small Cocks Moisture Per cent	One-fourth Swat Cured then Cock Mediu Cocks Moistu Per ce
August	22	8						
		10	15.6	66.29				
		12	14.4	63.5	65.0	65.0		
		2	13.6	61.3	64.4	64.6	62.0	62.0
		4	12.4	57.5	62.1	63.6	60.5	61.5
		6	12.0	56.5	61.5	62.5	60.0	60.0
August	23	8	14.1	62.8	63.0	63.0	61.0	59.5
		10	13.2	60.0	60.5	62.5	59.5	59.0
		12	12.0	56.0	58.5	61.0	57.5	58.5
		2	10.8	51.5	57.0	60.0	55.5	57.5
		4	10.0	47.5	55.0	59.0	54.0	56.5
		6	9.2	43.0	52.5	58.0	52.5	55.5
August	24	8	9.4	44.0	53.0	58.0	51.5	54.0
		10	9.2	43.0	51.0	56.5	50.0	52.5
		12	8.5	38.0	50.0	55.5	48.5	52.0
		2	8.0	34.0	48.5	55.0	47.5	51.0
		4	7.5	30.0	47.6	54.5	46.0	50.8
		6	7.2	26.5	47.0	53.5	45.0	50.0
August	25	8	7.2	26.5	47.5	52.5	44.0	49.5
		10	7.1	25.5	45.5	52.0	43.0	49.0
		12	7.0	24.5	44.0	51.5	41.5	48.5
		2	6.9	23.5	42.5	50.5	40.5	48.0
		4	6.8	22.7	41.5	50.0	39.0	47.0

Table XVI.

of moisture in alfalfa at stated intervals as indicating
which the hay gave up its moisture when windrowed immed-
ng, as compared with hay cocked immediately and with hay
before cocking. Series of August 22, 1927.

Cocked Immediately		One-fourth Swath Cured then Cocked		One-half Swath Cured then Cocked		Three-fourths Swath Cured then Cocked	
Small Cocks	Medium Cocks	Small Cocks	Medium Cocks	Small Cocks	Medium Cocks	Small Cocks	Medium Cocks
Moisture	Moisture	Moisture	Moisture	Moisture	Moisture	Moisture	Moisture
Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
65.0	65.0						
64.4	64.6	62.0	62.0				
62.1	63.6	60.5	61.5				
61.5	62.5	60.0	60.0				
63.0	63.0	61.0	59.5				
60.5	62.5	59.5	59.0				
58.5	61.0	57.5	58.5				
57.0	60.0	55.5	57.5	44.5	45.0		
55.0	59.0	54.0	56.5	41.0	42.0		
52.5	58.0	52.5	55.5	38.5	39.5		
53.0	58.0	51.5	54.0	37.0	38.5		
51.0	56.5	50.0	52.5	35.5	37.0		
50.0	55.5	48.5	52.0	33.5	35.5		
48.5	55.0	47.5	51.0	31.0	34.0		
47.6	54.5	46.0	50.8	29.0	33.0	27.0	27.0
47.0	53.5	45.0	50.0	28.0	32.0	26.0	26.5
47.5	52.5	44.0	49.5	27.5	31.0	24.0	26.0
45.5	52.0	43.0	49.0	27.0	30.5	23.0	25.5
44.0	51.5	41.5	48.5	26.5	30.0	21.5	24.5
42.5	50.5	40.5	48.0	26.0	29.5	20.0	24.0
41.5	50.0	39.0	47.0	26.0	29.0	18.5	23.0
				25.5	28.0		

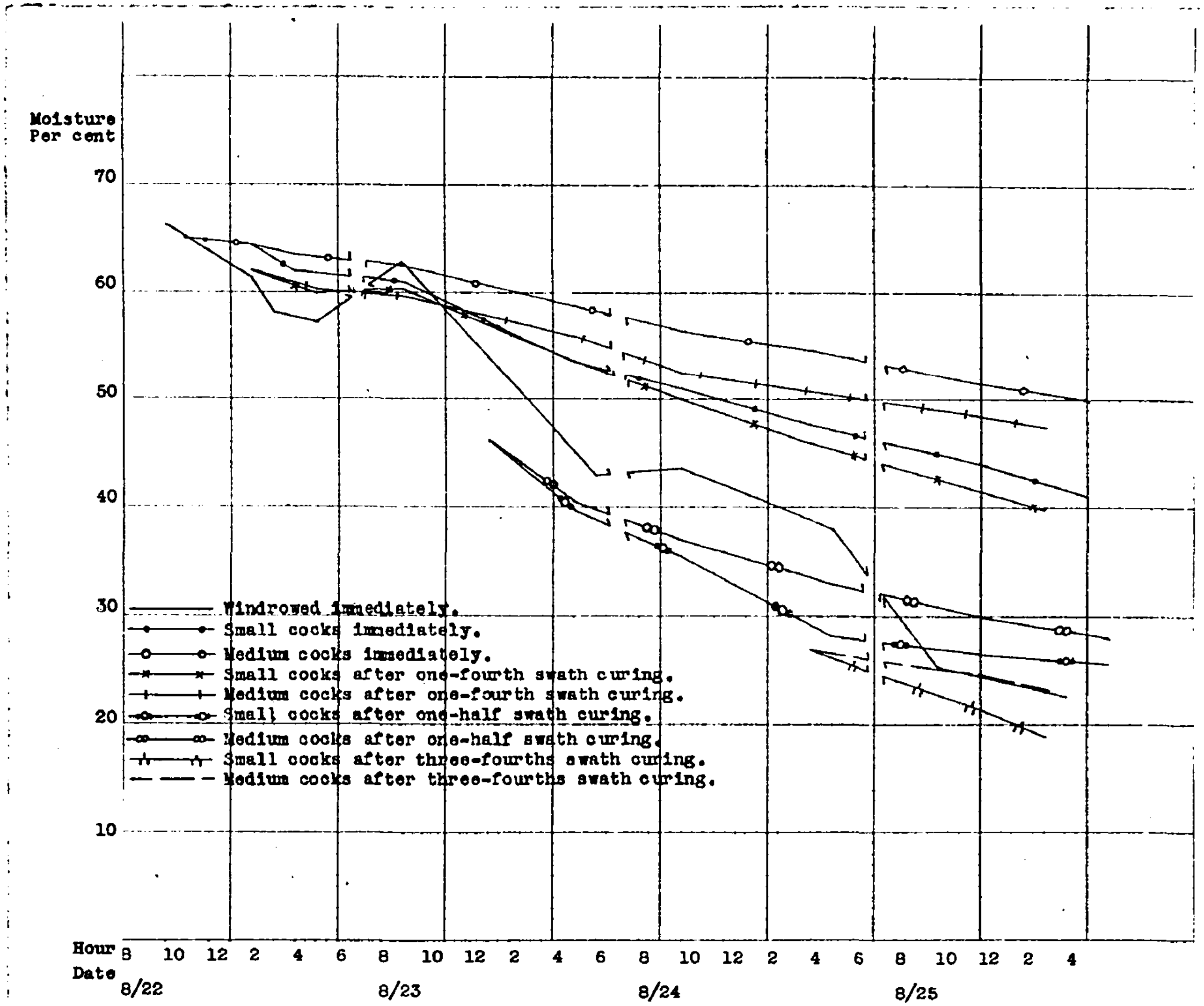

Fig. 16. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when windrowed immediately after cutting, as compared with hay cocked immediately and with hay partly swath cured before cocking. Series of August 22, 1927.

loss of moisture was checked when the hay was cocked. The check was more severe the larger the cock.

The series of August 23 (Table XVII,Figure 17) is consistent in that the partial swath curing gave the cocked hay such an advantage that the hay curing in the windrow during the cool weather did not catch up with it in degree of drying. It will be remembered that swath cured hay had reached 30 per cent moisture on August 24. This unexpectedly rapid curing of the hay in the swath caused the three-fourths swath cured hay to be reduced to 22 per cent moisture before it was cocked. Hay curing in the windrow was cured out more rapidly than hay cocked at once in either small or medium cocks, as a study of Figure 9 will show. Hay one-half cured, prior to windrowing and cocking in small cocks, has dried to 30 per cent moisture in 22 hours which is 11 hours previous to the windrow curing hay and 4 hours before the hay placed in medium sized cocks after similar swath curing.

Cocking of the hay always resulted in a very marked delay in the rate of curing. The larger the cocks of hay made the slower was the rate of curing. Green hay in medium to large cocks was inclined to settle compactly together, to heat somewhat, and to lose its green color,

Table XVII.

The percentage of moisture in alfalfa at stated interva
the rapidity with which the hay gave up its moisture when
iately after cutting, as compared with hay cocked immediat
partly swath cured before cocking. Series of August 23, 1

Month	Day	Hour	Windrowed Immediately		Cocked Immediately		One-half Swat Cured then Coc	
					Small Cocks	Medium Cocks	Small Cocks	Medi Cock
			Weight Pounds	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moistu Per ce
August	23	8						
		10						
		12						
		2	15.5	68.4	68.4	68.4		
		4	14.4	66.0	67.5	68.0		
		6	13.2	63.0	67.0	67.5		
August	24	8	13.2	63.0	65.5	66.5		
		10	12.2	60.0	64.5	65.0		
		12	11.1	55.5	63.5	64.5		
		2	9.8	50.0	62.0	64.0	40.0	40.0
		4	8.9	45.0	60.9	63.3	38.0	38.5
		6	8.6	43.0	60.0	62.0	36.0	37.0
August	25	8	8.6	43.0	59.0	61.5	34.0	35.5
		10	8.4	41.5	58.0	60.5	33.0	34.0
		12	8.2	40.0	57.0	60.0	31.0	33.0
		2	7.9	38.0	56.0	59.0	29.5	32.0
		4	7.7	36.0	53.5	58.5	27.5	30.0
		6	7.4	34.0	53.5	58.0	26.0	28.5
August	26	8	7.4	34.0	53.0	57.5	24.5	27.0
		10	7.1	30.9	52.6	57.2	22.5	25.5
		12	6.9	29.0	51.5	57.0	20.0	23.0
		2	6.8	27.5	50.5	56.0	16.0	20.5
		4	6.6	25.8	49.4	55.3	11.6	17.0

Table XVII.

centage of moisture in alfalfa at stated intervals as indicating
ty with which the hay gave up its moisture when windrowed immed-
er cutting, as compared with hay cocked immediately and with hay
th cured before cocking. Series of August 23, 1927.

Windrowed Immediately		Cocked Immediately		One-half Swath Cured then Cocked		Three-fourths Swath Cured then Cocked	
		Small Cocks	Medium Cocks	Small Cocks	Medium Cocks	Small Cocks	Medium Cocks
Weight Pounds	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent
15.5	68.4	68.4	68.4				
14.4	66.0	67.5	68.0				
13.2	63.0	67.0	67.5				
13.2	63.0	65.5	66.5				
12.2	60.0	64.5	65.0				
11.1	55.5	63.5	64.5				
9.8	50.0	62.0	64.0	40.0	40.0		
8.9	45.0	60.9	63.3	38.0	38.5		
8.6	43.0	60.0	62.0	36.0	37.0		
8.6	43.0	59.0	61.5	34.0	35.5		
8.4	41.5	58.0	60.5	33.0	34.0	22.0	22.0
8.2	40.0	57.0	60.0	31.0	33.0	21.0	21.5
7.9	38.0	56.0	59.0	29.5	32.0	19.0	20.0
7.7	36.0	53.5	58.5	27.5	30.0	17.0	18.5
7.4	34.0	53.5	58.0	26.0	28.5	15.0	17.0
7.4	34.0	53.0	57.5	24.5	27.0	13.0	18.0
7.1	30.9	52.6	57.2	22.5	25.5	11.0	14.5
6.9	29.0	51.5	57.0	20.0	23.0	8.5	13.0
6.8	27.5	50.5	56.0	16.0	20.5	5.5	10.0
6.6	25.8	49.4	55.3	11.6	17.02	2.5	7.8

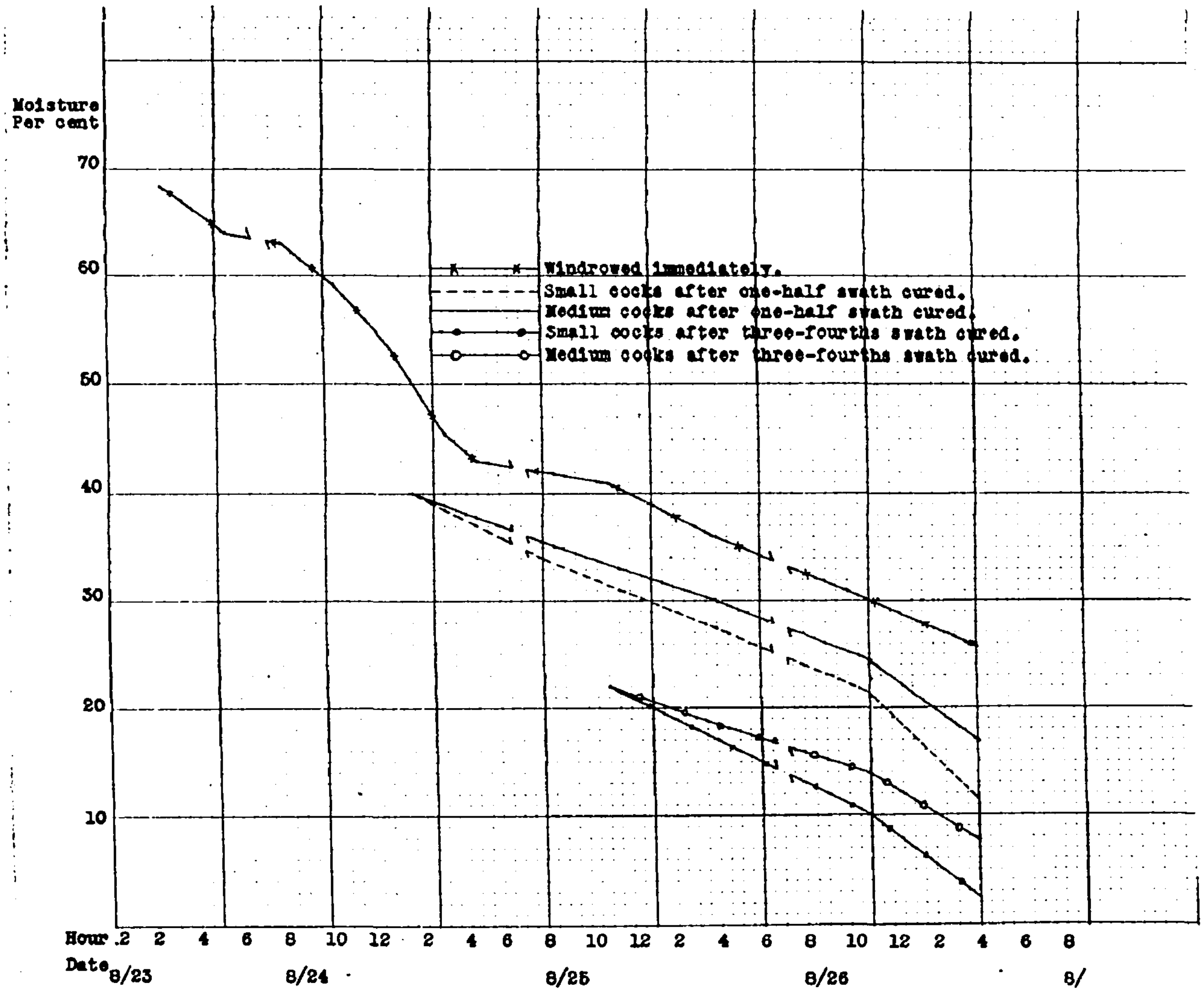

Fig. 17. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when windrowed immediately after cutting, as compared with hay cocked immediately and with hay partly swath cured before cocking. Series of August 23, 1927.

except in the outer 4 or 5 inches of the cock. If cocking is delayed until the hay is one-fourth or one-half cured the delay in curing is not so marked as the piles of hay do not settle so compactly as to interfere seriously with the drying of the hay. The hay cocked immediately after cutting in the small cocks produced an excellent grade of hay under favorable curing conditions. Where the curing was long delayed by poor drying conditions, the entire outside of these small cocks lost their color and the quality of the hay was not good. In poor curing weather the larger cocks of hay made after one-half swath curing seemed best. Under these conditions the hay in the center of the cocks made excellent hay while that on the outside became weathered. The percentage of this weathered hay was less than occurred in either the small cocks or in the hay cured in the windrow.

The elapsed hours of time from cutting to the point where hay with 30 per cent moisture was found is given for each of the series.

Method of curing	July 7	July 8	Aug 22	Aug 23
Windrowed Immediately	18	12	30	32
Small Cocks Immediately	24	20	76	81
Medium Cocks immediately	40	--	117	118
$\frac{1}{4}$ Swath cured then Small Cocks	24	15	52	--
$\frac{1}{4}$ Swath cured then Medium Cocks	40	--	72	--
$\frac{1}{2}$ Swath cured then Small Cocks	22	10	28	22
$\frac{1}{2}$ Swath cured then Medium Cocks	30	12	36	26
$\frac{3}{4}$ Swath Cured then Small Cocks	--	--	28	16
$\frac{3}{4}$ Swath Cured then Medium Cocks	--	--	28	16

These data show very strikingly the usual tendency for small cocks to cure out ahead of the medium ones and for hay cocked early before appreciable drying has taken place to dry exceedingly slow. This green hay in medium cocks smashes itself into a compact mass through which the air cannot circulate. The partial swath curing prevents this packing and curing continues fairly rapid in this hay when cocked.

D. The Rate of Curing Hay in Windrow with and without Turning.

The desirability of turning the windrow with the tail end of the rake was tested in each of four series of field experiments. In measuring the effect of turning the windrow, areas were weighed in two windrows, side by side, one of which was turned once during the curing process and the other not turned. The windrows were turned by driving the side-delivery rake alongside, so that the tail end of the rake caught the hay and turned it just half over. Four series of comparisons were made.

In the series of July 7 the effect of turning the windrow was tested in hay windrowed at once, in hay one-fourth swath cured, one-half swath cured, and three-fourths swath cured before windrowing. In each of the four comparisons five areas not turned were compared with five areas in which the windrow was turned. The series of July 8 was a replication of that of July 7 except that the three-fourths swath cured stage was not included, and three areas were weighed in each trial instead of five. In the series of August 22 the general method followed was the same as in the previous studies but somewhat more extensive. Four windrows were made immediately after cutting. One of these was not turned at all; one was turned when the hay in the windrow was one-fourth cured; one when the hay was one-half cured, and one when the hay was three-fourths cured. Three windrows were made when the hay in the swath was one-fourth cured, one was not turned at all, one was turned when the windrowed hay was one-half cured, and one when three-fourths cured. Two windrows were made when the hay in the swath was one-half cured. One of these was not turned at all while the other was turned when the hay was three-fourths cured.

The series of August 23 was a replication of that of August 22. The weights and moisture percentages recorded in Tables XVIII to XXI inclusive are averages for five weighings in the series of July 7 and three weighings in the other series.

In the series of July 7, it will be noted that the hay cured out during the first day at practically the same rate, whether the windrows were turned or not. Hay that was windrowed immediately and not turned dried out practically at the same rate as that in the turned windrow. At the end of the test there was no difference in the moisture content of the hay in the two windrows. Where the hay was one-fourth cured in the swath then windrowed the hay in the windrow that was turned dried to 30 per cent moisture one-half hour before that in the windrow not turned. At the end of the test the turned windrow had one per cent less moisture than the one not turned. When windrowing was done after the hay was one-half swath cured the hay in the turned windrow dried to 30 per cent moisture two hours before that in the windrow that was not turned. At the end of the experiment the hay in the turned windrow had 6 per cent less moisture than the hay in the one not turned.

In the series of July 8, (Table XIX and Figure 19) the hay cured completely in the windrow without turning lagged behind the turned windrow very slightly, drying to 30 per cent moisture 15 minutes later and containing $1\frac{1}{2}$ per cent more moisture at the end of the experiment. When the hay was windrowed after being one-fourth swath cured the turned windrow dried to 30 per cent moisture two hours before that not turned although for a time after windrowing it contained 5 per cent more moisture. This early difference is very likely due to an error in weighing. Hay windrowed after being one-half swath cured dried out as fast in the windrow not turned as in the one that was turned. At no time was there a greater difference than 1 per cent moisture between the two methods.

Table XVIII.

The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when the windrow was turned during the curing process as compared with hay windrowed and the windrows not turned. Series of July 7, 1927.

Month	Day	Hour	Windrowed Immediately		One-fourth Swath Cured Windrowed		One-half Swath Cured Windrowed		Three-fourths Swath Cured Windrowed	
			Not Turned	Turned	Not Turned	Turned	Not Turned	Turned	Not Turned	Turned
			Moisture	Moisture	Moisture	Moisture	Moisture	Moisture	Moisture	Moisture
			Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
July	7	8	67.00	67.00						
		10	63.50	63.50						
		12	60.50	60.50						
		2	58.00	58.00	57.50	57.50				
		4	53.50	54.00	52.02	52.02	52.50	52.50		
		6	49.50	50.00	48.5	48.5	49.5	49.0		
July	8	8	46.93	46.07	46.00	46.5	47.0	46.56		41.5
		10	42.0	42.5	43.00	43.0	43.0	37.5	38.0	37.5
		12	36.0	37.0	37.5	36.5	38.0	30.5	30.0	27.5
		2	28.36	28.99	32.5	29.5	32.5	23.59	25.7	21.0
		4	21.64	21.6	29.5	25.5	28.0	22.5	21.5	19.0
		6			25.0	23.0	25.0	19.5	20.0	19.0
		8			22.0	21.0	23.5	16.5	18.5	19.0
					21.5	20.5	23.0	15.5	17.5	19.0

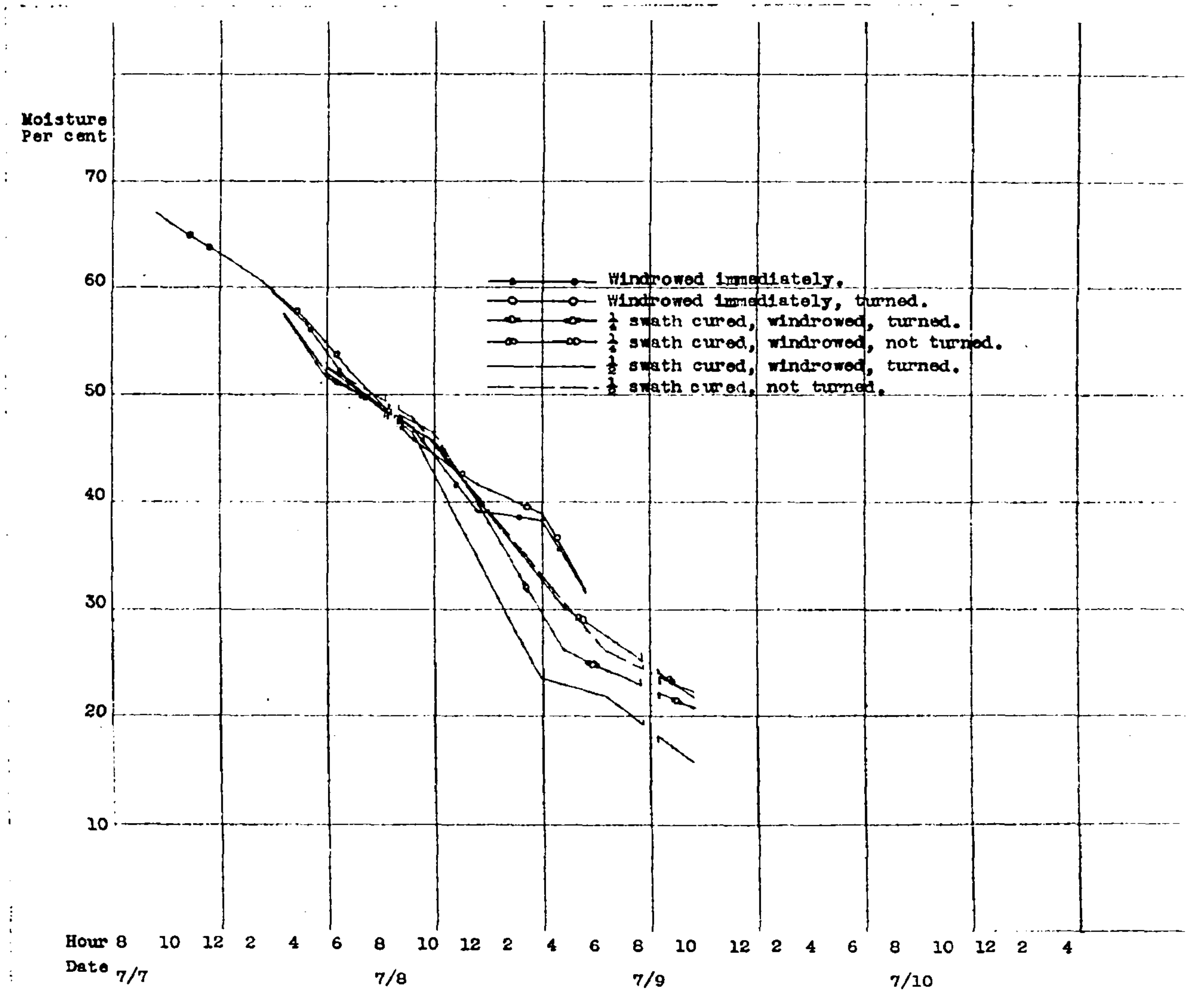

Fig. 18. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when the windrow was turned during the curing process as compared with hay windrowed and the windrows not turned. Series of July 7, 1927.

Table XIX.

The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when the windrow was turned during the curing process as compared with hay windrowed and the windrows not turned. Series of July 8, 1927.

Month	Day	Hour	Windrowed Immediately		One-fourth Swath Cured Windrowed		One-half Swath Cured Windrowed	
			Not Turned	Turned	Not Turned	Turned	Not Turned	Turned
			Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent
July	8	8						
		10	60.5	60.5				
		12	56.32	54.80	53.5	53.5		
		2	50.5	48.5	47.0	51.5		
		4	44.5	43.7	42.06	49.80	36.11	36.11
		6	40.0	37.7	38.55	37.25	32.43	31.13
July	9	8	35.96	32.34	32.85	27.46	25.06	25.31
		10	29.37	26.77	29.09	23.94	22.07	21.06
		12	26.50	25.35	26.52	21.56	19.38	19.75
		2	25.75	24.31	21.5	19.80	19.00	19.5
		4						

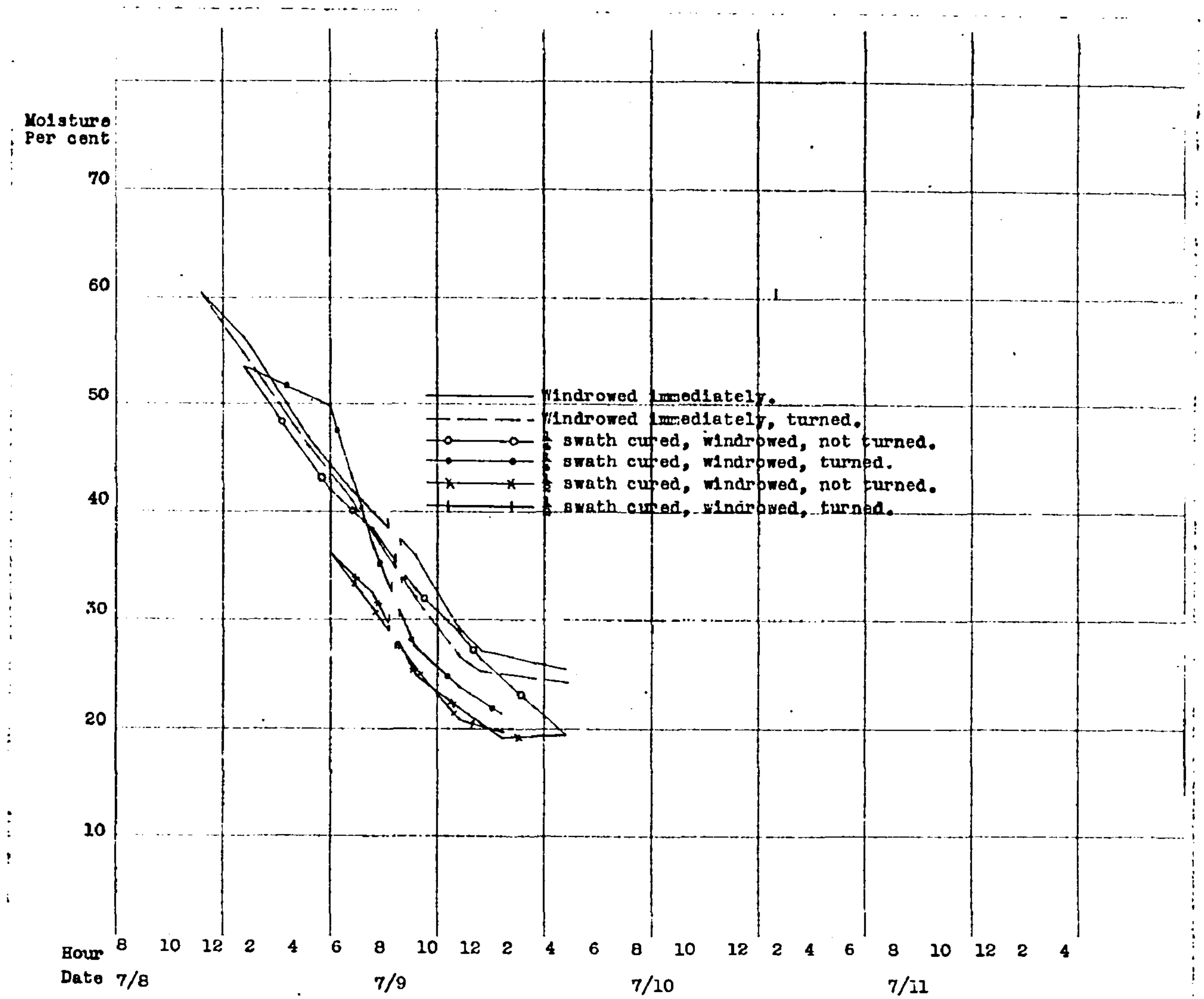

Fig. 19. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when the windrow was turned during the curing process as compared with hay windrowed and the windrows not turned. Series of July 8, 1927.

In the series of August 22, (Table XX, Fig 20) the effect of turning the windrow at various times in the curing is compared with the windrow not turned. In this experiment the moisture content of the hay in the windrow not turned, the one turned at one-fourth cured, and the one turned at one-half cured, did not differ more than two per cent during the first two days. On the third and fourth days the behavior was erratic. The windrow that was not turned lagged behind in rate of drying, being two hours later in reaching 30 per cent moisture than the one turned when one-fourth cured, and two hours earlier than the one turned at one-half cured. At the end of the experiment the windrow turned at one-fourth cured had 19 per cent moisture while the one not turned at one-fourth cured had 22 and the one turned at one-half cured contained 29 per cent. Throughout the four days the hay in the windrow that was turned when three-fourths cured dried faster than the other three and had 16 per cent moisture at the end of the experiment.

A study of Figure 21 shows that the three windrows made when the hay was one-fourth cured, the one not turned and the ones turned at one-half and at three-fourths cured, respectively, were erratic in their small variations.

Table XX.

Comparison of the Rates of Curin
out the Windrow Being Turned Over.

Month	Day	Hour	Windrowed Immediately				
				Turned at			
			Not Turned	One-fourth Cured	One-half Cured	Three-fourths Cured	Not Turn
			Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moist Per c
August	22	8					
		10	66.3	66.3	66.3	66.3	64.
		12	63.5	65.5	64.5	63.5	62.
		2	61.3	64.1	63.5	60.8	56.
		4	57.5	58.0	59.0	56.0	53.
		6	56.5	56.0	55.0	53.5	52.
August	23	8	62.8	62.8	62.8	62.0	62.
		10	60.0	58.5	59.5	56.0	56.
		12	56.0	53.7	55.0	50.5	48.
		2	51.5	49.5	51.5	47.5	45.
		4	47.5	46.5	48.3	44.5	43.
		6	43.0	43.5	44.5	42.0	40.
August	24	8	44.0	43.5	44.5	42.0	40.
		10	43.5	39.0	40.0	38.0	40.
		12	38.0	35.5	37.0	33.5	34.
		2	34.0	31.5	33.5	30.0	30.
		4	30.0	28.0	30.5	26.5	26.
		6	26.5	25.5	29.0	23.0	22.
August	25	8	26.5	25.5	29.0	23.0	22.
		10	25.5	23.5	28.5	21.0	20.
		12	24.5	21.5	28.5	19.5	19.
		2	23.5	20.0	28.5	18.0	18.
		4	22.7	18.8	28.9	16.5	17.

Table XX.

ison of the Rates of Curing Alfalfa With and With-
indrow Being Turned Over.

mediately		One-fourth Swath Cured			One-half Swath Cured	
ned at			Turned at			Turned at
e-half ured	Three-fourths Cured	Not Turned	One-half Cured	Three-fourths Cured	Not Turned	Three-fourths Cured
isture r cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent
66.3	66.3	64.7				
64.5	63.5	62.0	63.5	64.0		
63.5	60.8	56.8	61.0	63.4		
59.0	56.0	53.3	59.3	59.6		
55.0	53.5	52.5	57.0	57.5		
62.8	62.0	62.0	62.7	62.9		
59.5	56.0	56.6	61.3	62.6		
55.0	50.5	48.5	51.0	53.5		
51.5	47.5	45.5	49.5	49.0	45.0	44.5
48.3	44.5	43.0	48.6	45.0	43.0	41.5
44.5	42.0	40.0	42.5	41.5	40.5	39.5
44.5	42.0	40.5	42.5	42.0	40.5	39.5
40.0	38.0	40.0	38.5	36.5	36.5	34.0
37.0	33.5	34.5	34.0	32.5	33.0	29.5
33.5	30.0	30.5	29.5	28.5	29.5	25.0
30.5	26.5	26.5	25.5	24.5	27.0	20.5
29.0	23.0	22.5	23.5	22.0	26.0	18.5
29.0	23.0	22.5	23.5	22.0	26.0	18.5
28.5	21.0	20.5	22.5	22.0	25.5	18.0
28.5	19.5	19.0	21.5	22.0	25.0	17.5
28.5	18.0	18.0	21.0	22.0	25.0	17.0
28.9	16.5	17.0	20.0	22.3	24.0	16.5

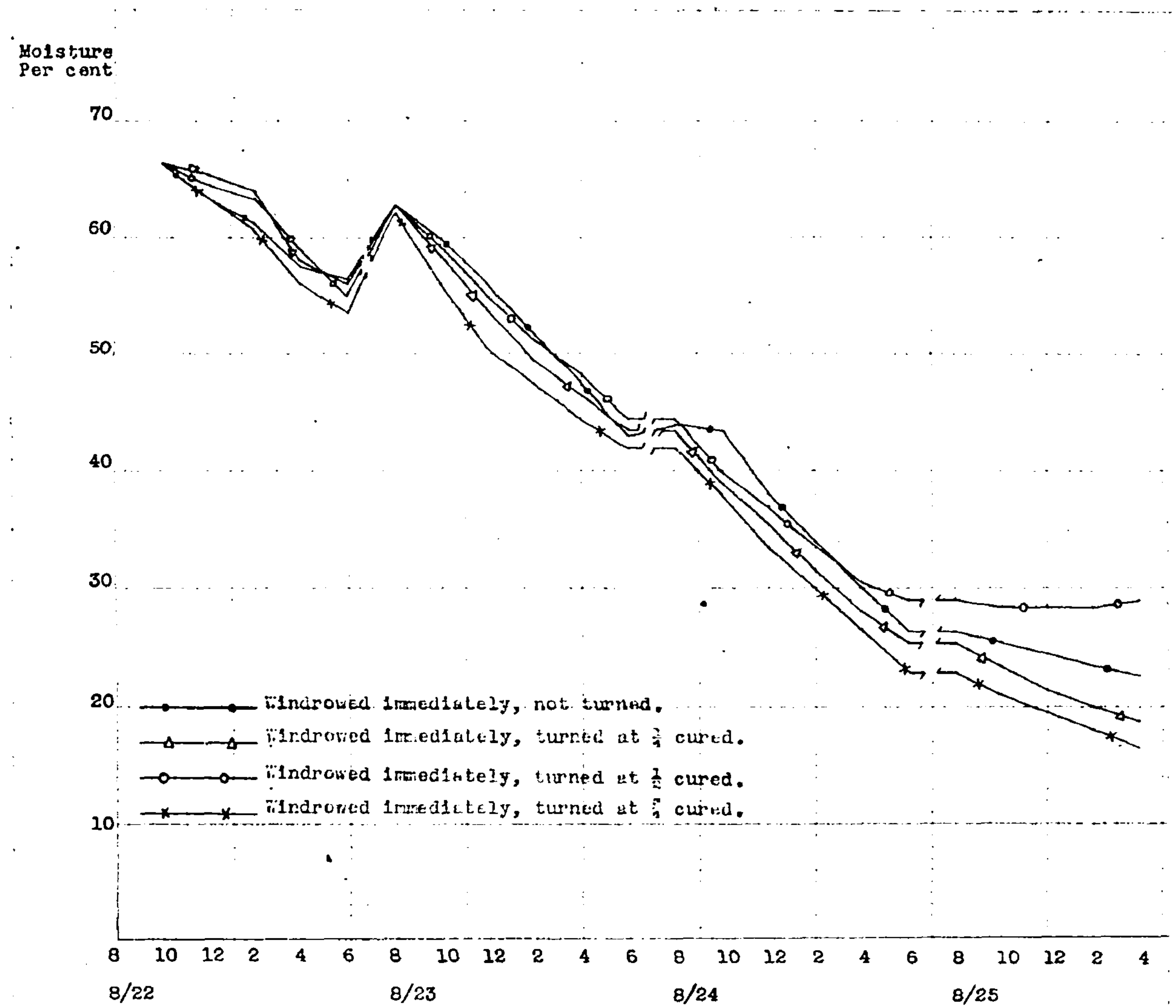

Fig. 20. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when the windrow was turned during the curing process as compared with hay windrowed and the windrows not turned. Series of August 22, 1927.

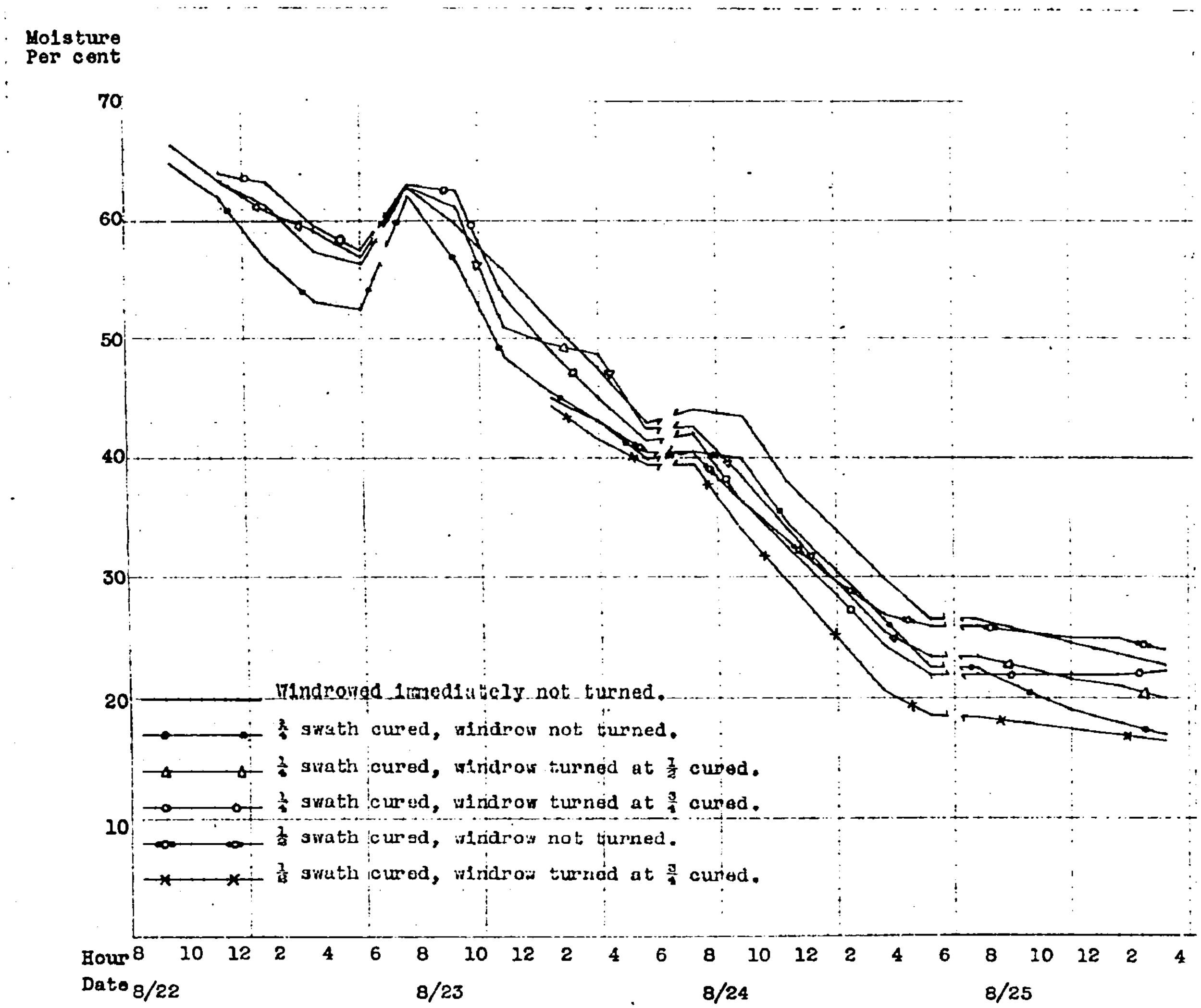

Fig. 21. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when the windrow was turned during the curing process as compared with hay windrowed and the windrows not turned. Series of August 22, 1927.

The windrow not turned dried rather consistently faster than the others although the difference was not great. During the first and second days of the test the windrows that were not turned contained as much as 5 per-cent less moisture than the others. On the third day the three were practically together, and at the end of the experiment the hay in the windrow not turned contained 17 per cent moisture, while those turned when one-half cured and three-fourths cured contained 20 and 22 per cent moisture, respectively. Hay in a windrow made after one-half swath curing and turned at three-fourths cured, dried out much more rapidly than a similar windrow that was not turned. The hay in the turned windrow contained 7 per cent less moisture than that in the one not turned, and at the end of the experiment the moisture content of the turned windrow was 16 per cent and of that not turned 24 per cent.

A study of the data in Table XXI. and Figure 22 indicates a rather marked uniformity through the experiment. The windrow not turned dried out slightly more rapidly than that turned at either one-fourth or three-fourths swath cured, while the one turned at one-half swath cured dried slightly faster than the one not turned.

Table XXI.

The percentage of moisture in alfalfa at statec
the rapidity with which the hay gave up its moist
turned during the curing process as compared with
windrows not turned. Series of August 23, 1927.

Month	Day	Hour	Windrowed Immediately				One-
				Turned at			
			Not Turned	One-fourth Cured	One-half Cured	Three-fourths Cured	Not Turned
			Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent
August	23	12					
		2	68.36	68.36	68.36	68.36	
		4	66.0	65.50	64.50	66	
		6	63.0	63.0	62.0	63.5	
August	24	8	63.0	63.0	62.0	63.5	
		10	60.0	60.0	57.4	60.4	53.82
		12	55.5	56.5	53.5	57.0	52.5
		2	50.0	52.5	49.0	54.0	47.0
		4	45.0	50.5	45.1	50.9	40.5
		6	43.0	48.0	42.5	48.5	35.0
August	25	8	43.0	48.0	42.5	48.5	35.0
		10	41.5	44.5	38.5	45.0	33.5
		12	40.0	42.0	36.0	43.0	31.5
		2	38.0	40.0	35	40.5	29.5
		4	36.0	37.5	34.0	38.0	27.5
		6	34.0	35.5	30.5	36.0	26.0
August	26	8	34.0	35.5	30.5	36.0	26.0
		10	30.9	33.33	30.4	32.19	24.5
		12	29.0	21.0	27.0	30.0	22.0
		2	27.5	28.5	26.5	28.0	19.5
		4	25.75	28.5	25.1	25.0	15.7
		6					

Table XXI.

of moisture in alfalfa at stated intervals as indicating
which the hay gave up its moisture when the windrow was
curing process as compared with hay windrowed and the
ed. Series of August 23, 1927.

Immediately urned at One-half Cured Moisture Per cent	Immediately urned at Three-fourths Cured Moisture Per cent	One-fourth Swath Cured Not Turned Moisture Per cent	One-fourth Swath Cured Turned at One-half Cured Moisture Per cent	One-fourth Swath Cured Turned at Three-fourths Cured Moisture Per cent	One-half Swath Cured Not Turned Moisture Per cent	One-half Swath Cured Turned at Three-fourths Cured Moisture Per cent
68.36	68.36					
64.50	66					
62.0	63.5					
62.0	63.5					
57.4	60.4	53.82	53.82	53.82		
53.5	57.0	52.5	50.0	49.0		
49.0	54.0	47.0	42.5	40.0	39.0	39
45.1	50.9	40.5	37.0	34.0	34.0	34
42.5	48.5	35.0	32.5	29.0	30.0	30.0
42.5	48.5	35.0	32.5	29.0	30.0	30.0
38.5	45.0	33.5	29.0	27.0	28.5	28.0
36.0	43.0	31.5	27.0	25.5	27.0	26.5
35	40.5	29.5	25.0	23.5	25.0	24.5
34.0	38.0	27.5	23.5	22.0	24.0	23.5
30.5	36.0	26.0	21.5	21.0	23.0	22.5
30.5	36.0	26.0	21.5	21.0	23.0	22.0
30.4	32.19	24.5	18.47	17.57	21.0	20.0
27.0	30.0	22.0	15.5	14.0	18.5	17.5
26.5	28.0	19.5	12.0	9.0	15.0	14.0
25.1	25.0	15.7	7.60	2.20	12.5	10.0

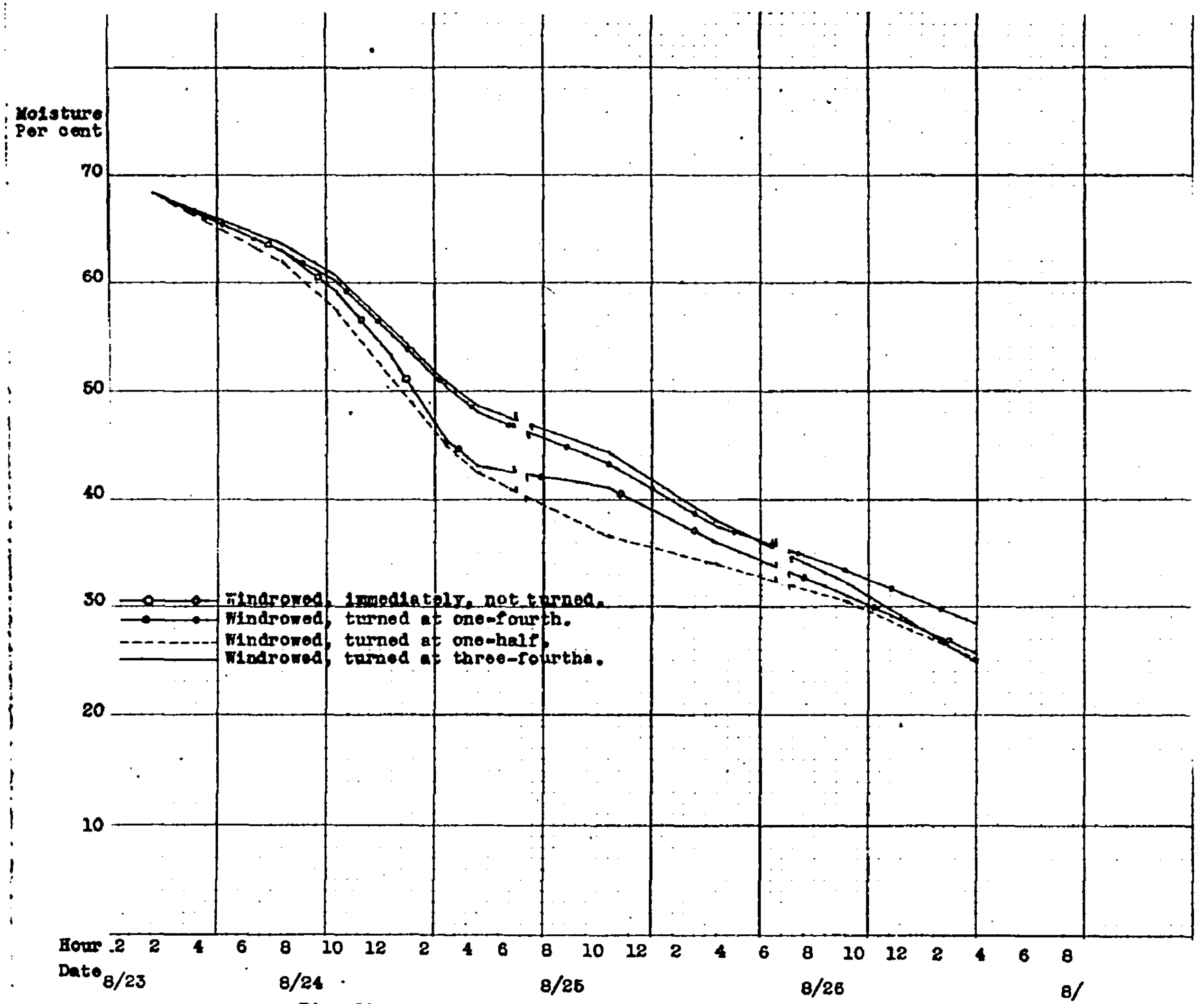

Fig. 22. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when the windrow was turned during the curing process as compared with hay windrowed and the windrows not turned. Series of August 23, 1927.

The differences were not large and the moisture content of three of the windrows was practically identical at the end of the experiment, while the hay in the windrow turned when one-fourth cured had 3 per cent more moisture than the others.

In Figure 23 it will be noted that hay windrowed at one-fourth swath cured and not turned dried more slowly than where the windrow was turned when one-half cured. The hay in the windrow turned at three-fourths cured dried out more rapidly than either of the others. There is quite an appreciable advantage in this series in time of curing in favor of turning the windrow. The windrow turned at three-fourths cured dried to 30 per cent four hours before that turned at one-half cured and 8 hours before that not turned. Practically no effect of turning the windrow can be noted in the hay windrowed at one-half cured.

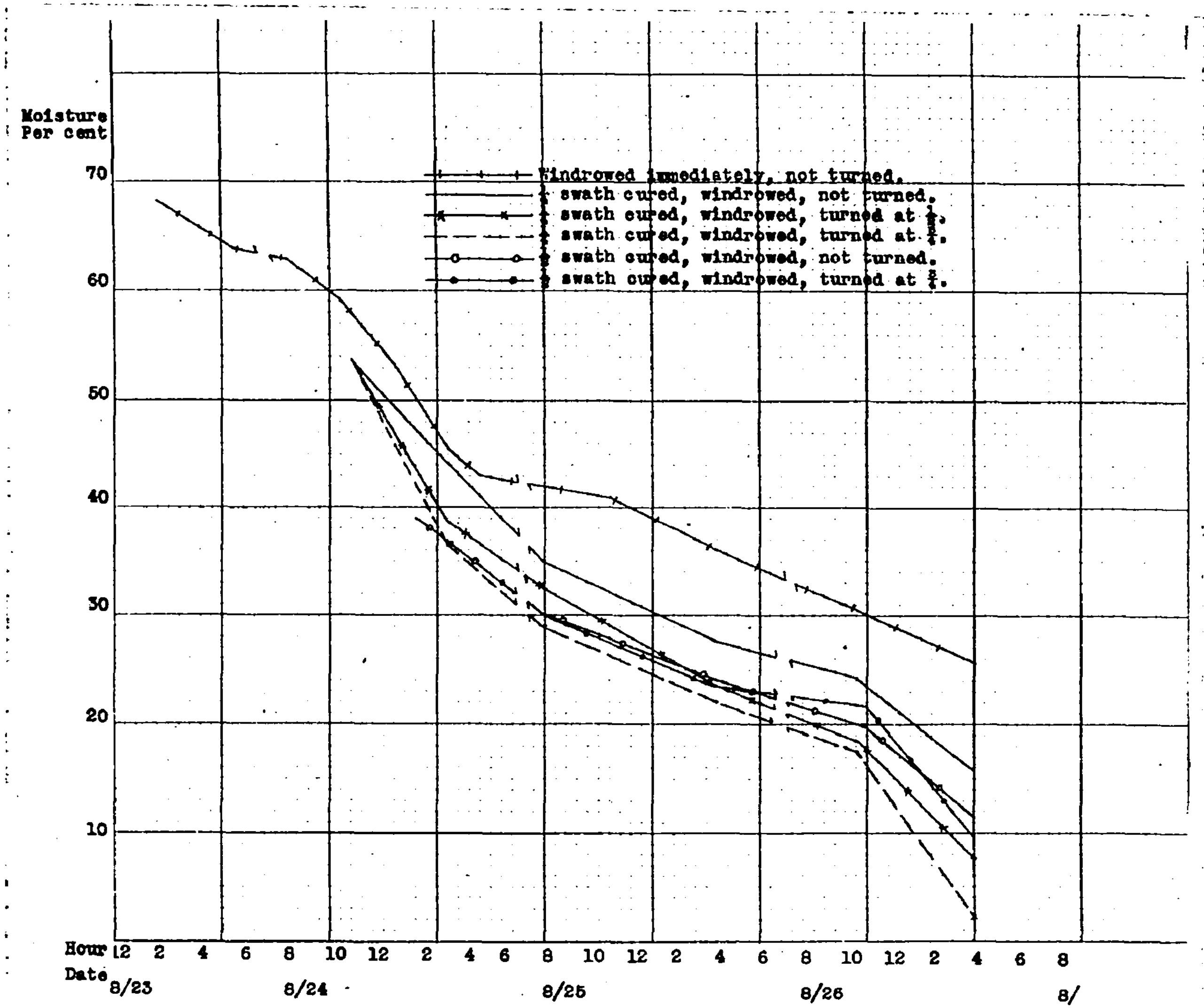

Fig. 23. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when the windrow was turned during the curing process as compared with hay windrowed and the windrows not turned. Series of August 23, 1927.

In all twenty comparisons of the rate of curing with and without the windrow being turned have been made. The twenty trials of turning the windrow are listed below, in each case the hours required to reduce the moisture content in the not turned windrow to 30 per cent is given first and just below it is the hours required to bring the moisture content to 30 per cent where the windrow was turned.

Method of curing	July 7	July 8	Aug. 22	Aug. 23
Windrowed immediately. Not turned	18.5	11	30	32
turned at $\frac{1}{4}$ cured	18.0	11	28	34
turned at $\frac{1}{2}$ cured			30	32
turned at $\frac{3}{4}$ cured			28	34
One-fourth Swath Cured. Not turned	18.0	10	28	24
turned at $\frac{1}{2}$ cured	16.0	8	27	20
turned at $\frac{3}{4}$ cured			27	16
One-half Swath cured. Not turned	18	9	28	16
turned at $\frac{3}{4}$ cured	16	9	26	16
Three-fourths Swath cured. Not turned	14	9	--	--
turned at 4/5 cured	13	9	--	--

In each test three areas in a windrow not turned and three in a windrow that was turned were used. In 12 of the trials the turned windrow had an average advantage of 2.3 hours over that of not turning. In 6 cases there was no difference, and in two cases the "not turned" had an average advantage of two hours over the turned areas.

As an average of 20 trials, the effect of turning was to hasten the curing of the hay by 1.1 hours. This apparent advantage in favor of turning the windrow may have been due, in part at least, to the loss of leaves as the moisture content was calculated from the loss in weight of the areas under consideration.

With heavy windrows and good curing conditions, a decided saving in time was effected by turning the windrow. When rains wet the hay in the windrows, turning checked the excessive bleaching of the hay and hastened curing.

E. The Rate of Curing Hay in the Swath, With and Without Tedding.

The effect of tedding hay was tested in each of four series of experiments. Two sets of areas were weighed in the swath, then the hay of one set tedded, and both sets weighed at regular intervals to determine the effect of tedding on the rapidity of curing.

Two tests were made with hay cut July 7, giving a direct comparison of hay that was tedded and hay that was not tedded. Four swaths of hay were allowed to remain in the swath until one-fourth cured when five areas were weighed in each swath and two swaths tedded while the remaining two were not tedded. When the hay was one-half cured the two pairs of swaths were windrowed separately for comparison. The hay from the different areas was weighed at regular intervals after the windrowing. Similar methods were used in a comparison between tedded swaths and those not tedded, with the hay windrowed when three-fourths cured.

The series of July 8 included four swaths of hay cured completely in the swath, two of which were tedded when the hay was one-half cured, and the other two not tedded. Four other swaths were allowed to remain in the swath until three-fourths cured, at which time two were tedded while the other two were windrowed when the hay was four-fifths cured.

More extensive tests of the effects of tedding were conducted in the series of August 22. Four sets of paired swaths were allowed to cure completely in the swath. The first set was not tedded, the second was tedded when the hay was one-fourth cured, the third when the hay was one-half cured, and the fourth when the hay was three-fourths cured. Four additional sets of paired swaths were allowed to cure until one-fourth cured when one set was windrowed and the other three tedded. One of the three tedded sets was windrowed when the hay was one-fourth cured, the second when one-half cured and the windrow turned when three-fourths cured. The fourth set was windrowed when three-fourths cured.

The series of August 23 is a replication of August 22 with the addition of one test. Hay tedded when one-half swath cured was compared with hay windrowed when one-half swath cured without tedding. The weights and moisture percentages for the four series of comparisons as recorded in Tables XXII to XXV, inclusive, are averages of five weighings in the series of July 7 and of three weighings for the other series.

The effect of the use of the tedder was tested in the series of July 7 on the two lots of hay shown in Table XXII. It will be noted that the rate of curing of the hay was not materially affected. The tedded hay had slightly more moisture except in the last few hours. The tedding was done prior to windrowing the hay. In the second test a very slight advantage in rate of drying is indicated in the data. In the series of July 8, Table XXIII indicates a rather erratic behavior in that first the not tedded, then the tedded hay dries out the more rapidly.

A more complete study of the effect of tedding was conducted in the series of August 22.

Table XXII.

The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when tedded at some time during the curing process as compared with hay not tedded. Series of July 7, 1927.

Month	Day	Hour	One-half Swath Cured Not Tedded Moisture Per cent	One-fourth Swath Cured Tedded Windrowed at One-half Moisture Per cent	Three-fourths Swath Cured Not Tedded Moisture Per cent	One-half Swath Cured Tedded Windrowed at Three-fourths Cured Moisture Per cent
July	7	8				
		10				
		12				
		2				
		4	52.50	52.5		
		6	49.50	52.0		
		8	47.0	50.5		
		10	43.0	46.5	38.0	35.0
		12	38.0	41.0	30.0	28.0
		2	32.5	36.5	25.7	23.5
		4	28.0	33.0	21.5	20.0
		6	25.0	29.0	20.0	15.5
		8	23.5	23.0	18.5	12.5
		9	20.5	19.0	17.5	10.5

Table XXIII.

The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when tedded at some time during the curing process as compared with hay not tedded. Series of July 8, 1927.

Month	Day	Hour	Swath Cured Completely: Not Tedded	Swath Cured Completely: Tedded at One-half Cured	Three-Fourths Swath Cured: Not Tedded	Three-Fourths Swath Cured: Tedded Windrowed at Four-fifths Cured
			Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent
July	8	8				
		10	59.7	59.7		
		12	51.0	53.7		
		2	42.5	44.0		
		4	36.1	36.5		
		6	36.2	31.9		
July	9	8	30.5	24.5	27.5	27.5
		10	20.2	23.8	24.3	22.5
		12	19.4	21.1	20.3	19.7
		2	18.7	20.5	18.5	19.1

The data in Table XXIV and in Figure 24 indicate very clearly that tedding hay did not materially influence the rate of drying of the hay. The hay cured completely in the swath dried out faster than that which was tedded when either one-fourth, one-half or three-fourths cured. The greatest difference in moisture content is noted at the end of the experiment when hay not tedded had 18 per cent, that tedded at one-fourth cured had 24 per cent, at one-half, 23 per cent, and tedded at three-fourths, 19 per cent.

In Figure 25 it will be noted that hay one-fourth swath cured, not tedded, cured out more rapidly than hay tedded at one-fourth cured and windrowed when one-half cured, or hay tedded at one-fourth and windrowed when three-fourths cured. There was practically no difference between the tedded swaths, but the one not tedded was 10 per cent drier during the second day.

Tedding tests made during the series of August 23 are reported in Table XXV. In Figure 26 the effect of tedding swath curing hay is indicated. It will be observed that there is practically no difference until the evening of the second day at which time the swath not tedded is the most nearly cured, followed in order by swaths tedded at one-fourth, at one-half and at

Table XXIV.

The percentage of moisture in alfalfa at stated i
the rapidity with which the hay gave up its moisture
time during the curing process as compared with hay
August 22, 1927.

Month	Day	Hour	Swath Cured: Not Tedded: Weight Pounds	Swath Cured: Not Tedded: Moisture Per cent	Swath Cured: Tedded When 1/4 Cured: Moisture Per cent	Swath Cured: Tedded When 1/2 Cured: Moisture Per cent	Swath Cured: Tedded When 3/4 Cured: Moisture Per cent	Not Tedded: Moisture Per cent
August	22	8	18.2	69.7	69.70	69.70	69.70	
		10	16.3	66.3	67.0	67.0	67.0	64.7
		12	14.7	62.5	64.0	62.0	63.5	62.0
		2	12.8	57.0	58.5	58.0	57.5	56.8
		4	11.7	53.0	55.0	55.5	53.5	53.3
		6	11.5	52.0	54.5	54.0	53.5	52.5
August	23	8	14.8	62.8	62.2	63.3	62.3	62.0
		10	12.8	57.0	55.5	56.0	56.0	56.6
		12	10.8	48.9	48.5	51.0	51.5	48.5
		2	10.0	44.9	44.0	48.0	47.0	45.5
		4	9.4	41.5	40.0	45.0	44.5	43.0
		6	8.8	37.5	37.5	42.5	42.0	40.0
August	24	8	9.0	39.0	39.5	40.5	39.5	40.5
		10	8.9	38.1	39.5	39.5	36.4	40.0
		12	8.0	31.5	35.5	34.5	33.5	34.5
		2	7.6	27.5	32.0	33.0	33.0	30.5
		4	7.3	24.0	28.0	27.0	28.0	26.5
		6	7.0	21.0	24.5	24.5	26.5	22.5
August	25	8	7.0	21.0	24.5	23.5	24.5	22.5
		10	6.8	19.5	24.0	22.5	23.5	20.5
		12	6.8	18.5	23.5	21.5	22.0	19.0
		2	6.7	18.0	23.0	20.5	20.5	18.0
		4	6.7	17.8	22.7	18.9	19.2	17.0
		6						

Table XXIV.

of moisture in alfalfa at stated intervals as indicating which the hay gave up its moisture when tedded at some ring process as compared with hay not tedded. Series of

n Cured				One-fourth Swath Cured		
Tedded When			Not Tedded	Tedded at One-fourth Cured		
1/4 ured	1/2 Cured	3/4 Cured		Windrowed at 1/2 Cured	Windrowed at 1/2 Turned at 3/4	Windrowed at 3/4
isture r cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent
9.70	69.70	69.70				
7.0	67.0	67.0	64.7			
4.0	62.0	63.5	62.0	60.1	60.1	60.1
8.5	58.0	57.5	56.8	55.7	57.0	54.8
5.0	55.5	53.5	53.3	54.4	51.0	52.0
4.5	54.0	53.5	52.5	48.5	47.5	50.0
2.2	63.3	62.3	62.0	62.0	62.0	60.5
5.5	56.0	56.0	56.6	59.5	60.0	58.5
8.5	51.0	51.5	48.5	58.0	58.5	56.5
4.0	48.0	47.0	45.5	55.5	56.0	55.0
0.0	45.0	44.5	43.0	54.5	54.5	54.5
7.5	42.5	42.0	40.0	51.5	52.0	53.0
9.5	40.5	39.5	40.5	52.0	52.5	52.5
9.5	39.5	36.4	40.0	45.5	45.5	47.0
5.5	34.5	33.5	34.5	39.0	38.5	40.0
2.0	33.0	33.0	30.5	33.0	32.5	34.0
8.0	27.0	28.0	26.5	26.5	25.0	27.5
4.5	24.5	26.5	22.5	23.0	22.0	23.0
4.5	23.5	24.5	22.5	23.0	22.0	22.0
4.0	22.5	23.5	20.5	22.5	22.0	21.5
3.5	21.5	22.0	19.0	22.5	22.0	21.0
3.0	20.5	20.5	18.0	22.0	22.0	21.0
2.7	18.9	19.2	17.0	22.0	21.5	20.5

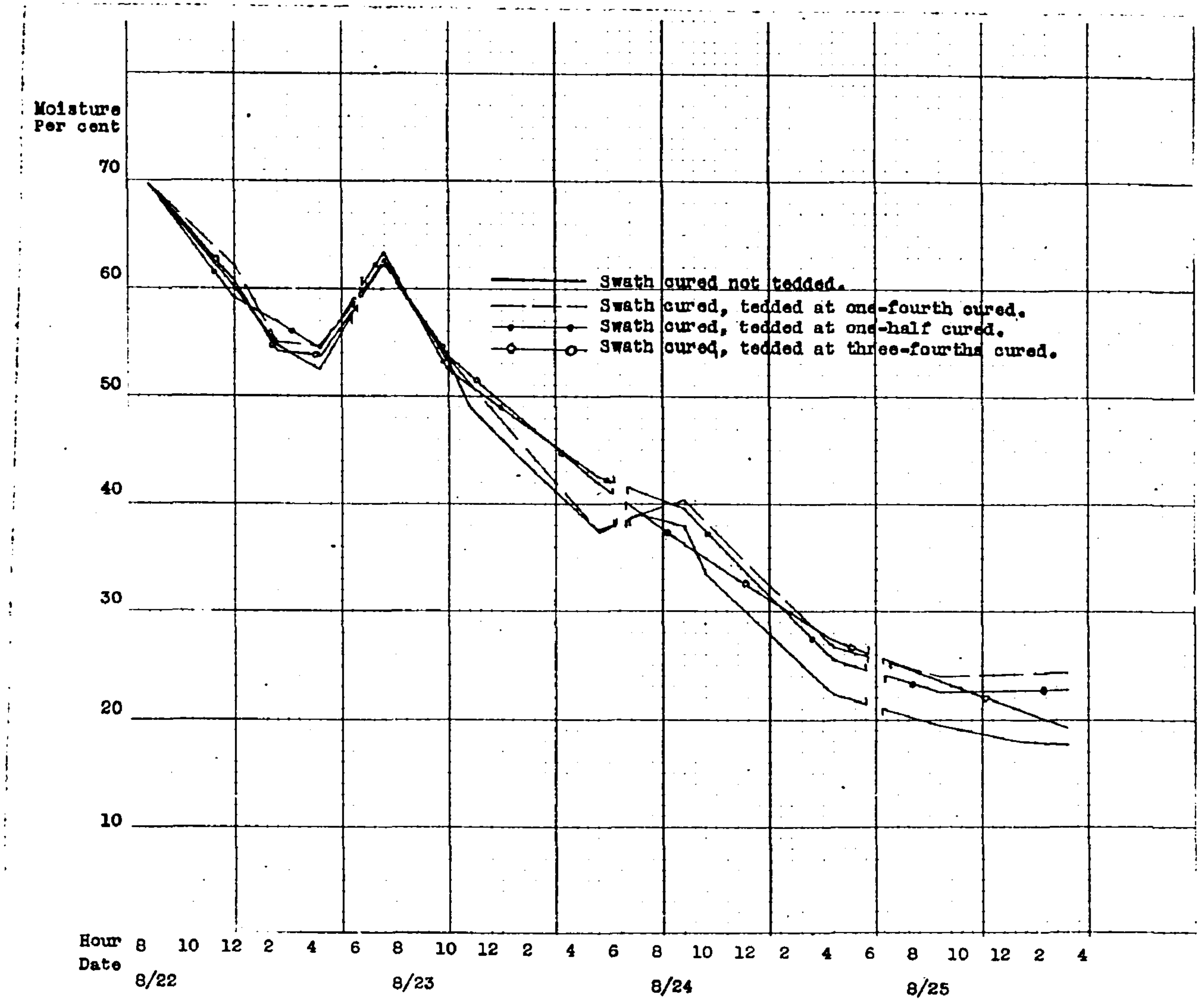

Fig. 24. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when tedded at some time during the curing process as compared with hay not tedded. Series of August 22, 1927.

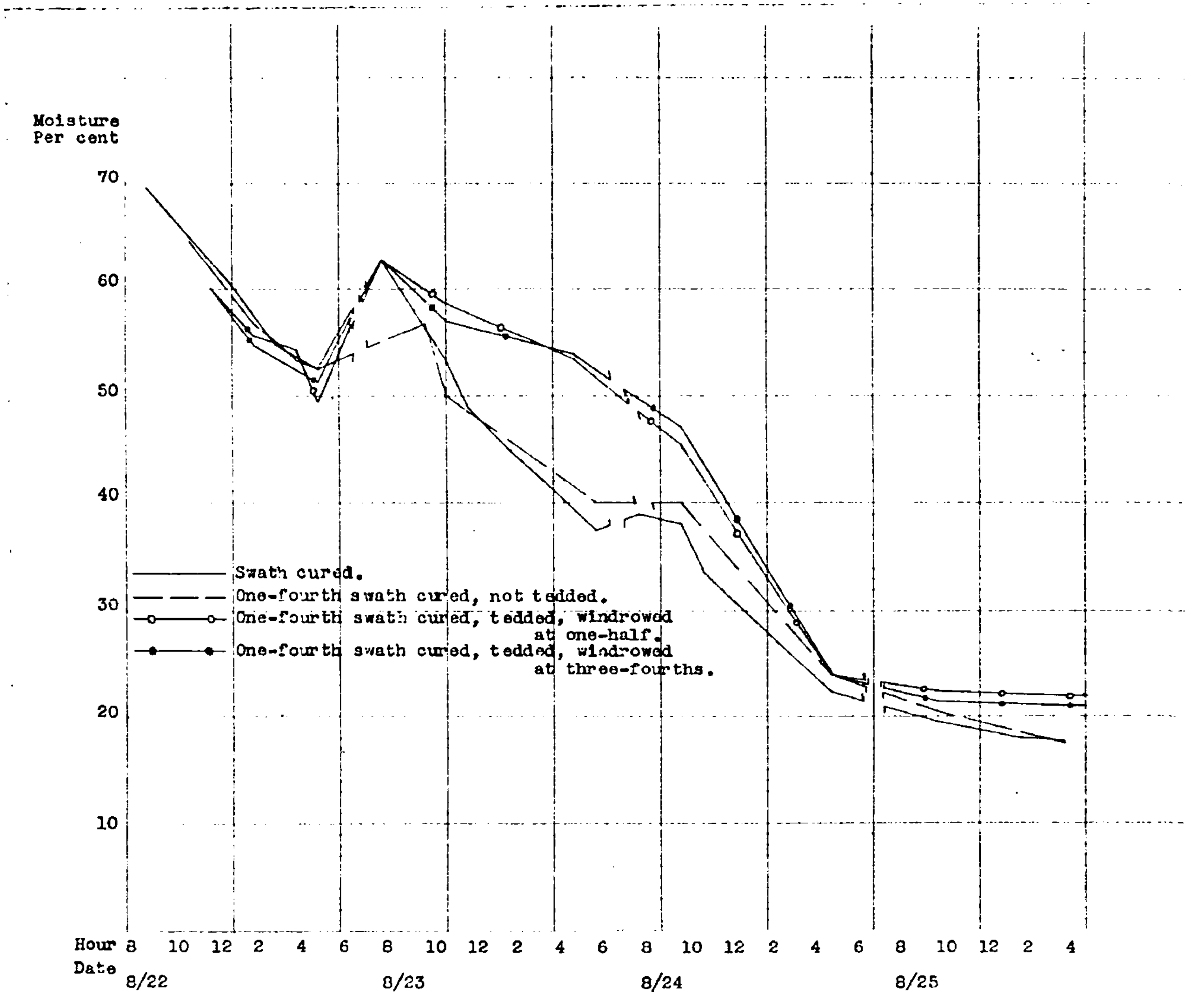

Fig. 25. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when tedded at some time during the curing process as compared with hay not tedded. Series of August 22, 1927.

Table XXV.

The percentage of moisture in alfalfa at stated
the rapidity with which the hay gave up its moistu
time during the curing process as compared with ha
August 23, 1927.

Month	Day	Hour	Swath Cured: Not Tedded: Weight Pounds	Swath Cured: Not Tedded: Moisture Per cent	Swath Cured: Tedded When 1/4 Cured: Moisture Per cent	Swath Cured: Tedded When 1/2 Cured: Moisture Per cent	Swath Cured: Tedded When 3/4 Cured: Moisture Per cent	1/2 Swath Cured Not Tedded: Moisture Per cent
August	23	12						
		2	13.5	68.36	68.36	68.36	68.36	
		4	11.0	61.18	61.1	60.47	62.53	
		6	9.9	57.0	57.0	56.5	58.0	
August	24	8	9.9	57.0	57.0	56.5	58.0	
		10	9.3	54.09	53.3	52.3	52.4	
		12	7.6	44.0	44.5	42.5	46.5	44.0
		2	6.6	35.5	37.5	35.0	39.5	39.0
		4	6.0	28.5	30.0	27.5	32.5	34.0
		6	5.4	20.5	22.5	24.0	26.0	30.0
August	25	8	5.4	20.5	22.5	24.0	26.0	30.0
		10	5.3	20.0	18.5	23.5	25.5	28.5
		12	5.3	19.0	18.3	21.0	23.0	27.0
		2	5.2	18.5	18.3	18.5	21.0	25.0
		4	5.2	18.0	18.3	16.5	19.0	24.0
		6	5.2	17.5	18.3	15.0	17.5	23.0
August	26	8	5.2	17.5	18.3	15.0	17.5	23.0
		10	5.1	16.27	18.3	12.7	15.8	21.0
		12	4.9	13.0	16.0	11.5	13.5	18.5
		2	4.7	9.5	14.0	10.0	11.5	15.0
		4	4.6	7.17	11.5	8.5	9.5	12.5
								11.48

Table XXV.

of moisture in alfalfa at stated intervals as indicating
which the hay gave up its moisture when tedded at some
ring process as compared with hay not tedded. Series of

ed	Tedded When		1/2 Swath Cured Not Tedded	1/4 Swath Cured Tedded Windrowed at		1/2 Swath Cured Then Tedded	
d	1/2 Cured	3/4 Cured		1/2 Cured	3/4 Cured		Windrowed at 3/4 Cured
ure ent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent	Moisture Per cent
36	68.36	68.36					
1	60.47	62.53					
0	56.5	58.0					
0	56.5	58.0					
3	52.3	52.4					
5	42.5	46.5	44.0	42.5			
5	35.0	39.5	39.0	37.78	39	39	39
0	27.5	32.5	34.0	31.0	34.0	34	34
5	24.0	26.0	30.0	25.5	29.0	31.5	31
5	24.0	26.0	30.0	25.5	29.0	31.5	31
5	23.5	25.5	28.5	23.0	27.0	28.5	29
3	21.0	23.0	27.0	21.0	25.5	26.5	28.5
3	18.5	21.0	25.0	19.0	24.0	24.0	27.0
3	16.5	19.0	24.0	17.0	22.5	21.5	25.5
3	15.0	17.5	23.0	16.0	20.0	19.0	24.5
3	15.0	17.5	23.0	16.0	20.0	19.0	24.5
3	12.7	15.8	21.0	15.6	17.5	17.5	24.0
0	11.5	13.5	18.5	12.5	14.0	15.5	22.5
0	10.0	11.5	15.0	9.5	10.5	12.5	20.0
5	8.5	9.5	12.5	7.0	6.0	10.0	17.5
			11.48				

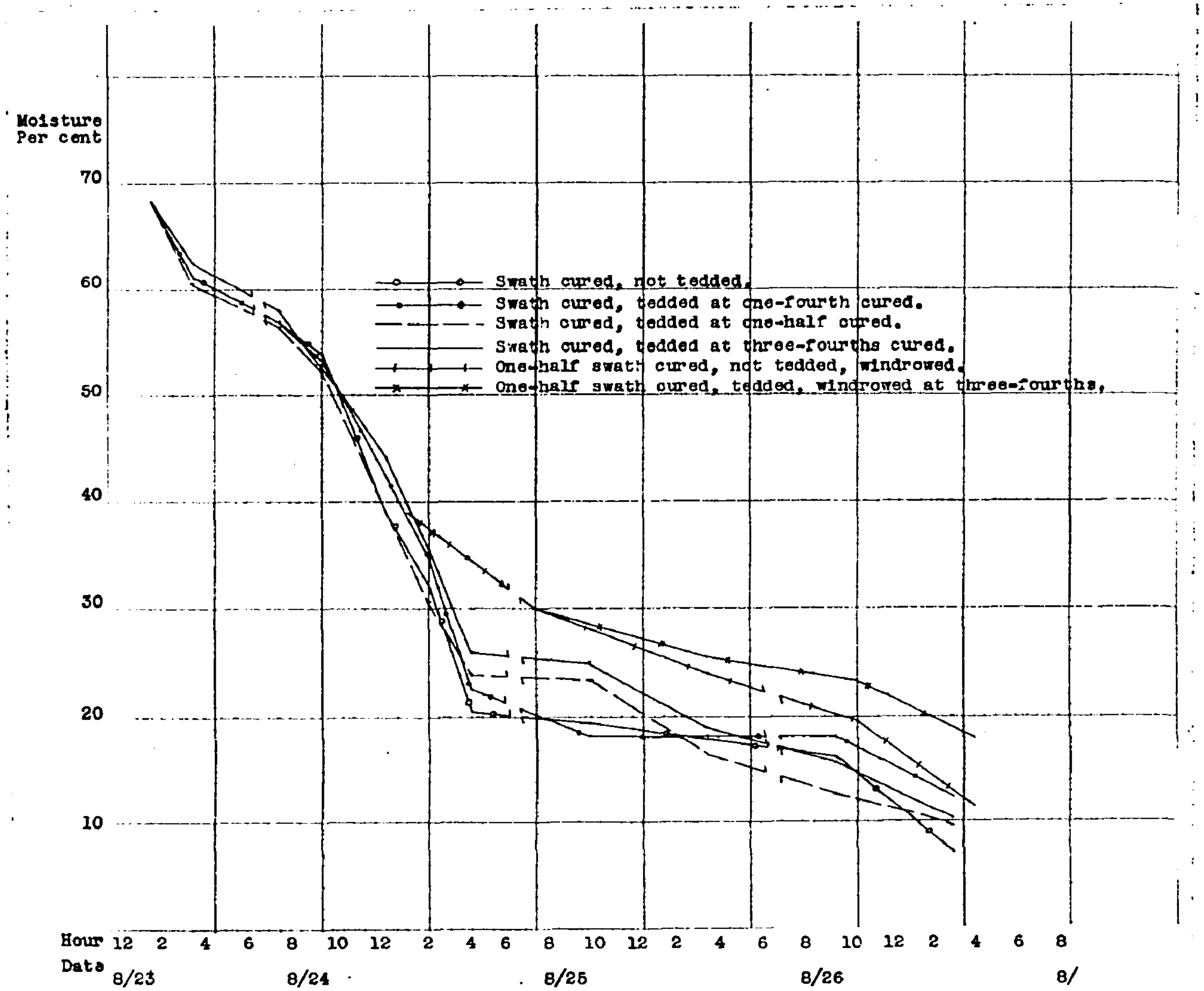

Fig. 26. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when tedded at some time during the curing process as compared with hay not tedded. Series of August 23, 1927.

three-fourths cured. The four swaths differ in moisture content by less than 6 per cent at the end of the experiment. It will also be noted that hay tedded after one-half swath curing dried at the same rate until the tedded swath was windrowed, after which it dried out much more slowly.

In Figure 27 an advantage is indicated for tedding hay when one-fourth swath cured and windrowed at either one-half or three-fourths cured, when compared with hay not tedded and windrowed at one-half cured. The tedded hay was dried to 30 per cent moisture 7 hours prior to that one-half swath cured and windrowed.

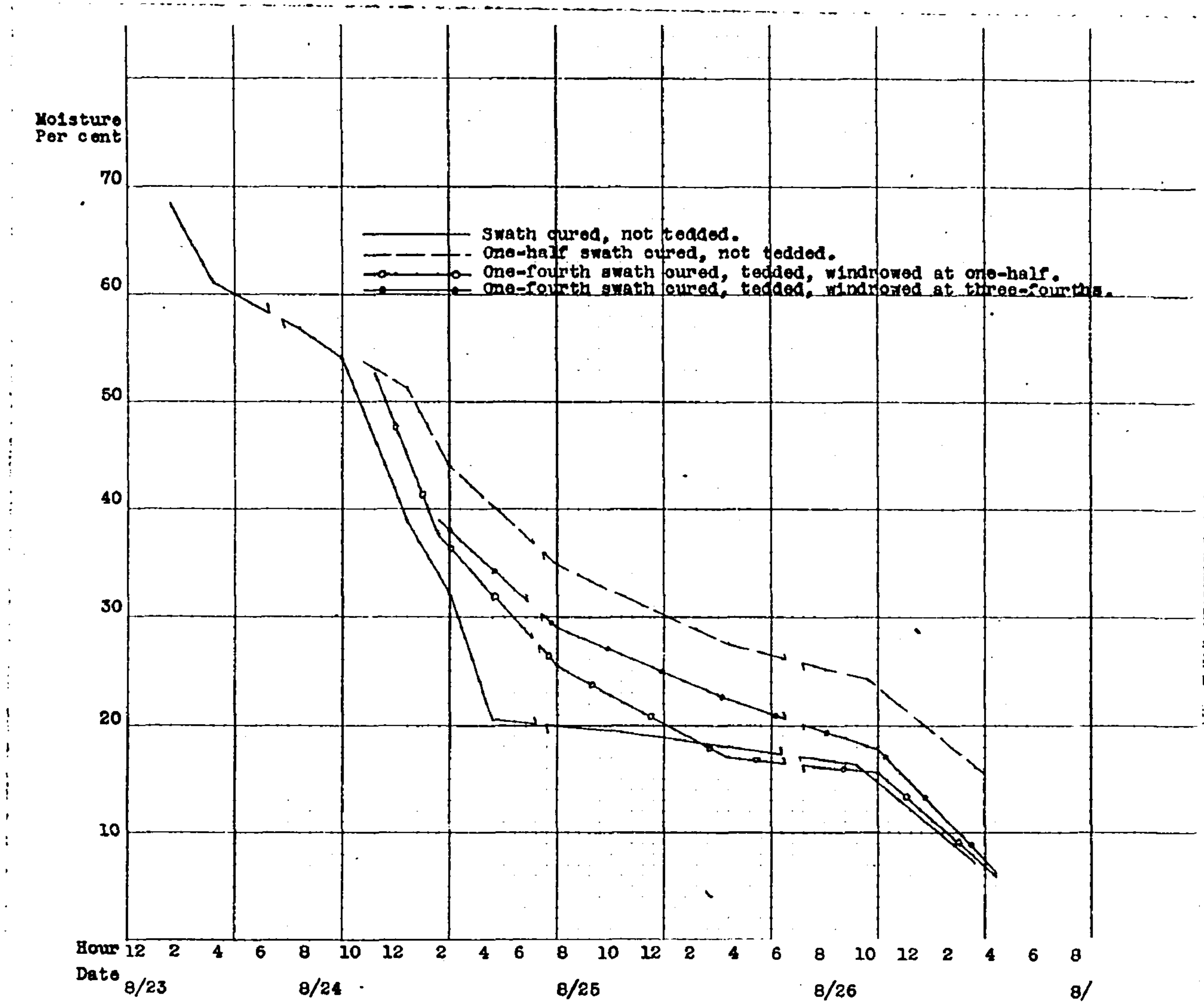

Fig. 27. The percentage of moisture in alfalfa at stated intervals as indicating the rapidity with which the hay gave up its moisture when tedded at some time during the curing process as compared with hay not tedded. Series of August 23, 1927.

In summarizing the tedding experiments the following comparisons have been made. The hours are the time required under each method of curing of reducing the moisture content to less than 30 per cent.

	Tedded	Not Tedded
Series of July 7		
One-half swath cured	22	20
Three-fourths swath cured	14	16
Series of July 8		
Full swath cured	10	12
Three-fourths swath cured	10	10
Series of August 22		
Full Swath Cured, Tedded at $\frac{1}{4}$	34	30
Full Swath Cured, Tedded at $\frac{1}{2}$	34	30
Full Swath Cured, Tedded at $\frac{3}{4}$	34	30
One-fourth Swath cured Windrowed at $\frac{1}{2}$	32	31
One-fourth Swath cured Windrowed at $\frac{1}{2}$ turned at $\frac{3}{4}$	32	31
One-fourth Swath cured Windrowed at $\frac{3}{4}$	32	31
Series of August 23		
Full swath cured, Tedded at $\frac{1}{4}$	14	13
Full Swath cured, Tedded at $\frac{1}{2}$	13	13
Full swath cured, Tedded at $\frac{3}{4}$	15	13
One-half swath cured Windrowed at $\frac{1}{2}$	16	16
One-half Swath cured Windrowed at $\frac{1}{2}$ turned at $\frac{3}{4}$	16	16
One-half Swath cured Windrowed at $\frac{3}{4}$	19	19

Tedding of hay was tested in 16 different comparisons, in 9 of which it delayed the curing an average of two hours. In two, it gave an advantage of two hours and in the others there was no difference in the time required to cure the hay. It seems evident that tedding is not a desirable practice under the conditions of these tests. There is a possibility that tedding would be advisable in extremely heavy swaths of hay if done about the time the top hay has wilted. In the heavy hay and with the slow curing that occurred in the series of August 23, tedding the hay early in the curing process seemed advantageous.

The Quality of the Hay as Influenced by the Method of Curing.

The measure of quality in hay does not lend itself readily to experimental methods. Two factors affecting quality have been measured in this experiment: "Color" and "Leafiness".

Color. Notes were taken on the color of the hay resulting from the different methods of curing. Five degrees of color were recognized with values as follows: (1) Excellent, meaning full green color; (2) Good, allowing a slight bleaching; (3) Medium, allowing considerable bleaching and a slight leaf loss; (4) Poor, some green color remaining but badly bleached or heated; (5) No green color, either gray or brown, weathered, molded or heated.

The standards for classification may have varied somewhat between series, but it is believed that in general the values given indicate the relative quality of hay cured by the different methods. The color estimates which were made at the time of the last weighings in the field are given in Table XXVI. Color estimates were made after a study of the hay from the weighed areas and from the larger areas in the field cured by the same methods.

Table XXVI.

Color values of hay cured by different methods.

Method of Curing	July 7	July 8	Aug. 22	Aug. 23	Totals
Windrowed immediately	2	2	3	1	8
Swath cured completely	3	3	4	2	12
¼ Swath cured, windrowed	2	2	2	1	7
½ Swath cured, windrowed	2	3	2	1	8
¾ Swath cured, windrowed	3	3	3	2	11
Cocked at once, Small Cocks	1	1	2	1	5
Cocked at once, Medium Cocks	4	-	3	3	-
¼ Swath cured, cocked, Small Cocks	1	1	2	-	-
¼ Swath cured, cocked, Medium Cocks	2	-	2	-	-
½ Swath cured, cocked, Small Cocks	2	2	2	1	7
½ Swath Cured, cocked, Medium Cocks	1	2	2	2	7
¾ Swath cured, cocked, Small Cocks	-	-	3	3	-
¾ Swath cured, cocked, Medium Cocks	-	-	2	2	-

The color scorings indicate that the practice of cocking in small cocks immediately after cutting or after one-fourth swath curing, gave the best quality of hay. The hay cured one-fourth in the swath then windrowed ranked next, with the hay windrowed immediately of practically the same quality. One-half swath curing resulted in better color than the three-fourths swath curing or full swath curing. The latter two methods are not to be recommended as means of producing high quality hay.

The series cut in the afternoon had good color regardless of the methods of curing. This also was observed in other tests in 1928 and 1929. This seems to be due to the re-absorption of the moisture by the dry leaves and their consequent softening during the overnight period. As a result of this softening, the hay may be handled in the early hours of the morning without leaf loss. The stems on the lower side of the swath or windrow may be brought up to the sun while those which had dried the previous afternoon are covered. If these stems and leaves, largely dried the previous day, are left exposed to the sun after the dew had dried off they will bleach. If the hay is largely in the windrow at this time it will not be disturbed while if it is in the swath, as would be the case with afternoon cutting, the hay will be windrowed as soon as the dew is off and the bleaching avoided.

Leafiness. The loss of leaves was determined for three of the series of experiments on methods of curing. The weighing device was used to weigh a sequence of areas in the swath, windrow, and cocks. These areas were then weighed again when cured. The hay was taken out of the windrows with a hay-loader equipped with a pan and canvas to catch the leaves as the hay was lifted off the ground and elevated to the wagon. These leaves were weighed and the percentage of the loss calculated. Table XXVII gives the percentage of the total hay lost as leaves when the hay was cured by different methods. The percentages are based on dry weight of the hay. In the series of August 22 and August 23, 1927, amounts of hay varying from 50 to 190 pounds were taken up by the loader for each determination. The determinations of August 15, 1928 were based on weighings of 25 to 50 pounds of hay each.

Hay cured in the swath was taken up out of the swath with a hay loader, also the small cocks, while the medium sized cocks were forked onto the rack and weighed in order to arrive at the loss of leaves.

Table XXVII.

The per cent of leaves lost from hay cured by the different methods.

Method of Curing	Aug 22 1927	Aug 23 1927	Aug 15 1928
Windrowed Immediately when cut	6.95	1.66	4.14
Windrowed, turned when ¼ cured	7.92	1.24	3.96
Windrowed, turned when ½ cured	7.64	2.12	5.18
Windrowed, turned when ¾ cured	9.85	2.88	8.12
Swath cured completely	9.30	13.20	7.32
Swath cured, tedded when ¼ cured	10.40	15.92	7.64
Swath cured, tedded when ½ cured	11.60	16.45	10.92
Swath cured, tedded when ¾ cured	12.00	19.66	13.12
¼ Swath cured, then Windrowed	9.40	3.82	6.02
¼ Swath cured, Windrowed, turned when ½ cured	9.30	3.98	
¼ Swath cured, Windrowed, turned when ¾ cured	11.10	3.07	
¼ Swath cured, tedded, windrowed when ½ cured	12.50	3.19	
¼ Swath cured, tedded, windrowed when ¾ cured	13.8	4.39	
½ Swath cured, then Windrowed	9.34	5.04	5.23
½ Swath cured, windrowed, turned when ¾ cured	11.96	10.06	
½ Swath cured, tedded, windrowed when ¾ cured	15.2	8.60	10.23
¾ Swath cured, then windrowed	14.0	6.63	7.48
Cocked immediately, small cocks	1.43	1.23	
Cocked immediately, Medium cocks	1.12	1.28	

It is quite possible that the indicated losses are lower than actually occurred as any loss prior to the weighing just before loading would not be included in the loss. General observations would indicate that the leaves did not fall appreciably until the hay was agitated. The agitation incident to weighing in some cases may have resulted in an appreciable loss.

It is evident that the smallest loss of leaves occurred when the hay was windrowed immediately after cutting or placed in cocks immediately. Cocking immediately is not considered a practical method of curing hay because of its cost and the time required for curing. Hay windrowed immediately and turned when one-fourth cured showed a low leaf loss, as did also hay one-fourth cured in the swath and then placed in windrows which were not turned. Turning the windrow when the hay was three-fourths cured caused an additional loss of 290, 1.22 and 3.98 per cent of the total hay in the form of leaves when compared with hay cured without the windrow being turned. This loss is entirely too great to be justified by the small saving in time credited to the turning of the windrow.

The effect on the leaf loss of turning or not turning the windrow was measured 15 times of which 11 show an appreciable additional loss of leaves with the turned windrow and four show a gain of less than 1 per cent.

The tedding of swath curing hay when the hay was $\frac{3}{4}$ swath cured resulted in an additional loss of 2.70, 6.46 and 5.80 per cent of the total hay as leaves, as compared with hay entirely swath cured without tedding. Fifteen comparisons of tedding and not tedding were made in which tedding resulted in an additional loss in 13 cases and practically the same loss in the other 2.

A further study of Table XXVI indicates the severity of the loss under complete swath curing, three-fourths swath curing and one-half swath curing. Hay $\frac{1}{4}$ swath cured before windrowing had but slightly larger leaf loss than hay windrowed immediately,and not so large a loss as windrowed immediately and turned when three-fourths swath cured.

<u>A Study of the Functioning of Alfalfa Leaves During the Curing Process.</u>

In the first experiment three sets of 100 gram samples of alfalfa were used. The first set consisted of 6 trays of alfalfa, three with whole plants and three with the leaves clipped from the stems. This set of trays was placed on a table in the laboratory out of any noticeable direct draft. The other sets consisted of two trays of whole plants and two with the leaves clipped from the stems. One of these sets was exposed on a north window ledge, while the other was placed in the sun outside the building. In all cases the clipped leaves were distributed around the stems in as nearly their normal position as possible. The trays, which were 12 inches square and made of screen wire, with covers for those exposed outside, were weighed at regular intervals. The experimental data are given in Table XXVIII.

It is evident that the plants with the leaves cut off dried as rapidly as the whole plant in the laboratory. The two groups of plants exposed on the trays on the window ledge cured at practically the same rate, one showing a slight advantage for a time and then the other. When curing in the sun neither the whole plants nor the plants with the leaves severed from the stems drying more rapidly than the others.

In another experiment a study was made to determine the effect of removing the leaves from portions of the plant, on the moisture content of the different parts.

Table XXVIII.

A Comparison of the Rate of Loss of Moisture in Whole Alfalfa Plants and in Plants with the Leaves Cut from the Stems, as Measured by the Calculated Per cent of Moisture at Stated Times during the Curing Period.

Month	Day	Hour	On Table in Lab.: Whole Plants	On Table in Lab.: Leaves Cut off	On Window Ledge: Whole Plants	On Window Ledge: Leaves Cut off	In the Sun: Whole Plants	In the Sun: Leaves Cut off
June	6	8	73.22	73.22	73.22	73.22	73.22	73.22
		11	67.3	68.6	69.3	67.3	63.0	62.6
		3	58.6	60.0	58.3	59.6	48.3	47.3
		5	55.3	56.0	54.2	56.3	43.6	43.0
June	7	8	55.6	53.3	52.3	51.6	40.3	42.0
		11	52.6	51.3	52.0	50.3	31.6	34.6
		3	43.3	41.3	39.6	42.3	20.0	23.3
		5	41.6	38.0	(2)	37.6(1)	18.6	19.0
June	8	8	42.0	43.0		38.6 "	20.3	20.6
		11	37.3	38.6		36.3 "	15.6	14.3
		3	29.6	31.6		29.3 "	12.6	14.3

(1) Only one sample

(2) Both samples destroyed.

Five twelve-inch trays with screen covers were used. The first tray contained 25 plants with leaves attached; the second, 25 stems from which the leaves had been clipped; the third, the leaves from the 25 plants in the second tray; the fourth, 25 plants with the leaves clipped from the top half of each stem; and the fifth, 25 plants with the leaves clipped from the bottom half of each stem.

The moisture content of the whole plants, top leaves, top stems, bottom leaves and bottom stems was determined at the beginning of the test. The same analysis was made of the plants in the four trays at the end of the test. The trays were exposed to the direct rays of the sun on a bench in the greenhouse.

The temperatures varied from 28 to 42°C. and the humidity varied from 30 to 42 per cent. The trays were weighed at indicated intervals and the moisture content of the material calculated as shown in Table XXIX.

The data show~~s~~ clearly that leaves alone lose moisture more rapidly than stems alone, as would be expected. Apparently the leaves of the top half of the plant caused a more rapid loss of moisture than the leaves of the bottom half. This can easily be accounted for by the fact that there were more leaves on the top

Table XXIX.

The influence of the leaves on the loss of moisture from the stems of alfalfa. July, 1930.

Month	Day	Hour	Leaves all on: Weight Grams	Leaves all on: Moisture %	Leaves all off: Weight Grams	Leaves all off: Moisture %	Leaves alone: Weight Grams	Leaves alone: Moisture %	Leaves off top half of plant: Weight Grams	Leaves off top half of plant: Moisture %	Leaves off bottom half: Weight Grams	Leaves off bottom half: Moisture %
July	1	10	69.25	70.2	35.5	68.3	24.5	74.5	40.0	69.9	45.5	68.7
		2	33.7	38.8	21.5	47.7	6.5	3.9	21.5	44.0	24.0	40.6
		4	30.8	32.9	20.3	44.4	6.3	3.9	20.0	39.8	22.3	35.9
		6	28.4	27.4	18.3	38.4	6.5	3.9	18.3	34.0	20.0	28.7
		9	28.0	26.4	18.0	37.5	7.0	10.7	18.0	33.1	19.5	26.9
July	2	3 PM	25.0	17.5	15.0	25.0	6.75	7.4	15.3	21.0	17.3	17.3
Final Moisture Content in Portions of Plant at the end of the Test.												
Top Stems				23.0		25.3			22	22.6		23.4
Bottom Stems				19.3		19.9				19.0		17.3
Top Leaves				6.11				4.8		---		6.2
Bottom Leaves				2.3				4.8		3.4		--

half to dry out and as the leaves lose water more rapidly than the stems the quantity of leaves influences the rate of drying. A study of the final moisture determinations indicated a slight variation at times but there is no tangible evidence in these data which would indicate that the functioning of the leaves lowers the moisture of the stems.

The presence or absence of the leaves did not seem to materially influence the moisture content of any portions of the stem. There was a slightly greater loss of moisture in each, the top and bottom portions of the stems, when the leaves were removed from these respective portions. No indication of the leaves "pumping" water from the stems is indicated in this experiment.

On July 8, 1930, alfalfa about one-tenth in bloom and 16 inches high was cut at 7 A. M. and the moisture content of various portions of the plant determined as soon as possible. The sampling for this determination of moisture was started at 7:30 and finished at 9 A. M. The extended period which was necessary accounts for the higher moisture content of some of the samples. The average moisture content as determined for triplicate samples was as follows:

Portion of the Plant	:Weight of :sample used	:Average Mois- :ture content
1. The entire plant	20 grams	71.2
2. Leaves from bottom half of plant	5 grams	72.2
3. Leaves from top half of plant	10 grams	68.0
4. The top half of stripped stem	20 grams	66.6
5. The bottom half of stripped stem	20 grams	66.2

To determine the rate of loss of moisture from the different parts of the plant, samples were placed on screen trays and weighed at regular intervals. The trays were made of screen wire, 12 inches square, with a one-inch flange turned up all around. A flat piece of screen served as a cover while the trays were being handled. Two samples were prepared of each portion of the plants included.

As the moisture samples for each method were taken the trays were prepared and weighed. The size of samples used were as follows: The entire plant, about 30 grams; leaves from the bottom half of the plant, about 7 grams; leaves from the top half of the plant, 25 grams; the top halves of the stripped stems, 40 grams; and the bottom half of the stripped stems, 25 grams.

One set of the trays was placed on racks in the greenhouse which were shaded from the sun with heavy brown paper. The other set was placed on top of the paper covered rack in the sun. When the trays were in place some of the unused alfalfa plants were spread on the benches near the trays for use in making moisture tests during the course of the experiment. The trays were weighed each hour from 10 A. M. to 9 P. M. the first day, and at two hour intervals thereafter until dry. Moisture samples were taken to check on the moisture content shown by the loss of weight in the tray of entire plants. The moisture percentages are given in Tables XXX and XXXI. The temperatures as an average of four thermometers in each lot of hay, are given for each time of weighing. The relative humidity varied between 24 and 30 per cent. The moisture content of the plants in each of the trays is shown graphically for the duration of the test in Figure 28 and Figure 29. At 1 P.M. July 10, at the conclusion of the experiment complete moisture determinations were made on the trays.

The sun cured plants dried too rapidly owing to the extremely high temperature and the low relative humidity. The weighings should have been at intervals of 10 or 15 minutes in order to picture the rate of loss

Table XXX.

The moisture content of different parts of the alfalfa plant as determined at regular intervals when the plants were dried in the sun. 1930.

Sample Exposure Month	Day	Hour	Entire Plant Moisture Percent	Bottom Stems Moisture Percent	Bottom Leaves Moisture Percent	Top Stems Moisture Percent	Top Leaves Moisture Percent	Temp. C°
July	8	10	71.2	66.2	72.3	68.0	72.3	57.0
		11	61.0	55.5	49.5	63.0	55.5	56.5
		12	52.3	46.0	24.4	56.9	41.2	57.0
		1	28.3	27.6	14.6	26.9	23.8	57.0
		2	22.5	15.5	14.6	15.5	14.0	56.5
		3	17.6	10.1	14.6	10.2	6.0	56.5
		4	15.8	10.1	1.8	7.5	6.0	46.5
		5	15.5	10.1	1.8	7.5	6.0	43.0
		6	15.7	10.1	1.8	7.5	6.0	39.0
		7	16.5	10.1	1.8	7.5	6.0	37.0
		8	17.0	10.1	1.8	8.0	6.5	32.0
		9	17.6	10.1	1.8	9.0	7.5	26.5
July	9	8	8.2	10.1	1.8	12.7	13.3	35.7
		10	3.1	1.1	1.8	1.8	10.2	51.0
		12	3.0	1.0	1.5	1.8	6.0	56.5
		2	2.6	0.4	0.0	1.8	6.0	55.5
		4	0.6	0.4	1.8	0.0	6.0	52.5
		6	0.6	0.4	1.8	1.8	6.0	36.0
		8	3.5	3.0	3.5	1.8	8.0	31.0
		9	5.5	4.2	4.65	1.8	9.4	29.0
July	10	1	0.6	0.4	1.8	1.8	6.0	39.5

Table XXXI.

The moisture content of different parts of the alfalfa plant as determined at regular intervals when the plants were dried in the shade. 1930.

Sample Exposure Month	Day	Hour	Entire Plant Moisture Percent	Bottom Stems Moisture Percent	Bottom Leaves Moisture Percent	Top Stems Moisture Percent	Top Leaves Moisture Percent	Temp. C°
July	8	10	71.2	66.2	72.3	68.0	72.3	39.7
		11	67.5	63.0	70.0	65.0	69.0	40.2
		12	64.6	60.2	67.5	62.8	65.4	42.0
		1	55.8	52.8	49.8	53.9	49.8	42.0
		2	48.0	48.0	32.0	48.0	37.5	41.5
		3	35.9	39.9	21.1	39.1	22.1	41.5
		4	31.7	36.2	8.0	39.1	22.1	40.0
		5	31.5	36.0	8.0	37.5	22.0	38.0
		6	31.5	35.5	8.0	37.0	21.5	37.0
		7	31.5	33.5	8.0	35.0	21.0	36.0
		8	31.5	32.0	8.0	33.5	20.5	32.0
		9	31.7	30.5	8.5	32.3	20.1	28.5
July	9	8	31.7	23.6	13.8	27.6	16.9	29.2
		10	19.5	12.8	8.0	20.8	16.9	38.5
		12	16.0	8.5	4.0	17.5	15.5	
		2	12.8	4.8	1.4	14.6	14.6	45.5
		4	4.3	4.8	1.4	4.6	5.6	43.0
		6	4.3	4.8	1.4	4.6	5.6	37.5
		8	6.0	4.8	4.0	7.0	8.0	33.0
		9	7.7	4.8	8.0	9.1	11.0	32.0
July	9	1	4.3	3.6	8.0	4.6	5.6	37.5

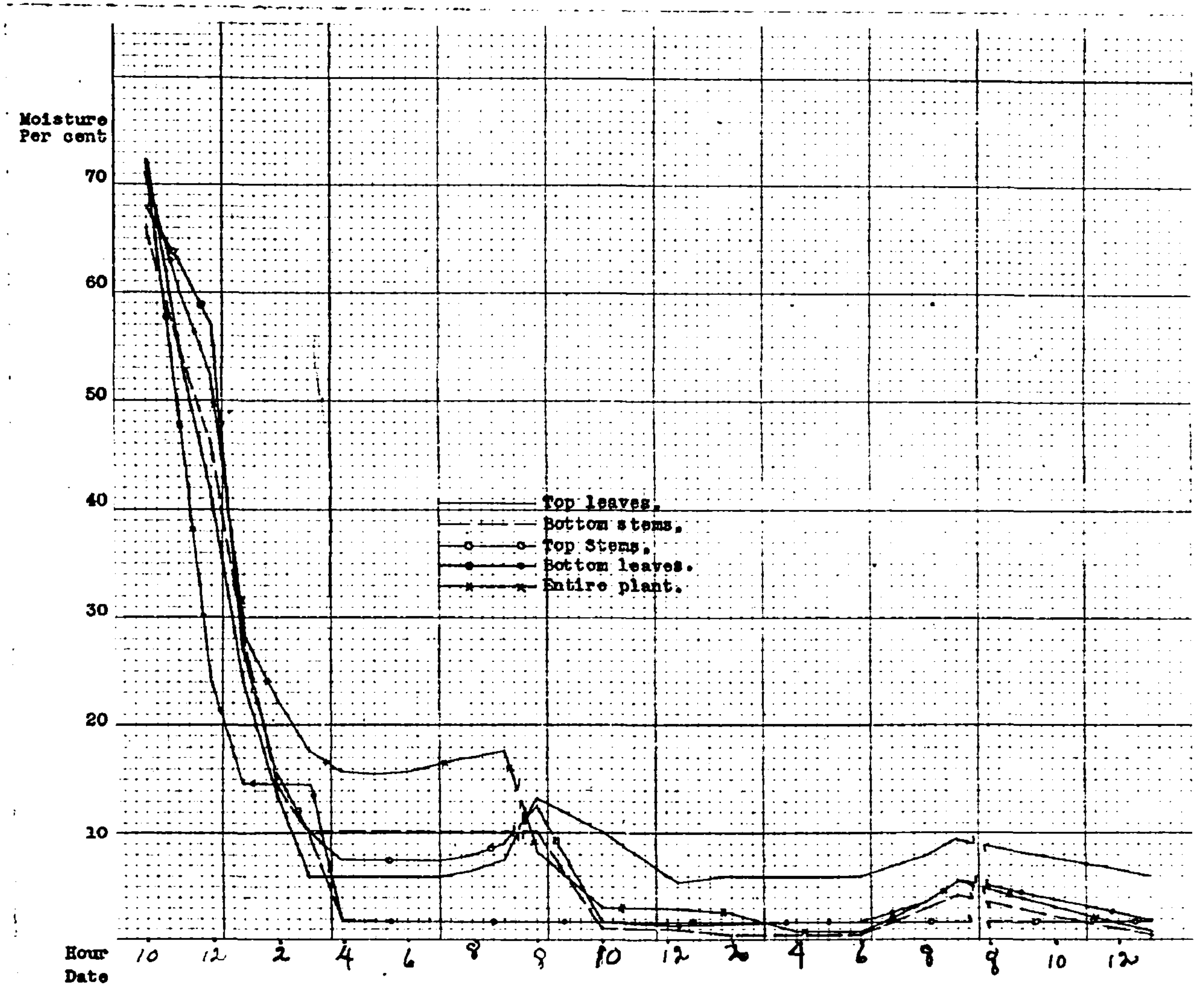

Fig. 28. The influence of the presence of the leaves on the rate of loss of moisture from the stems of alfalfa curing in the sun. 1930.

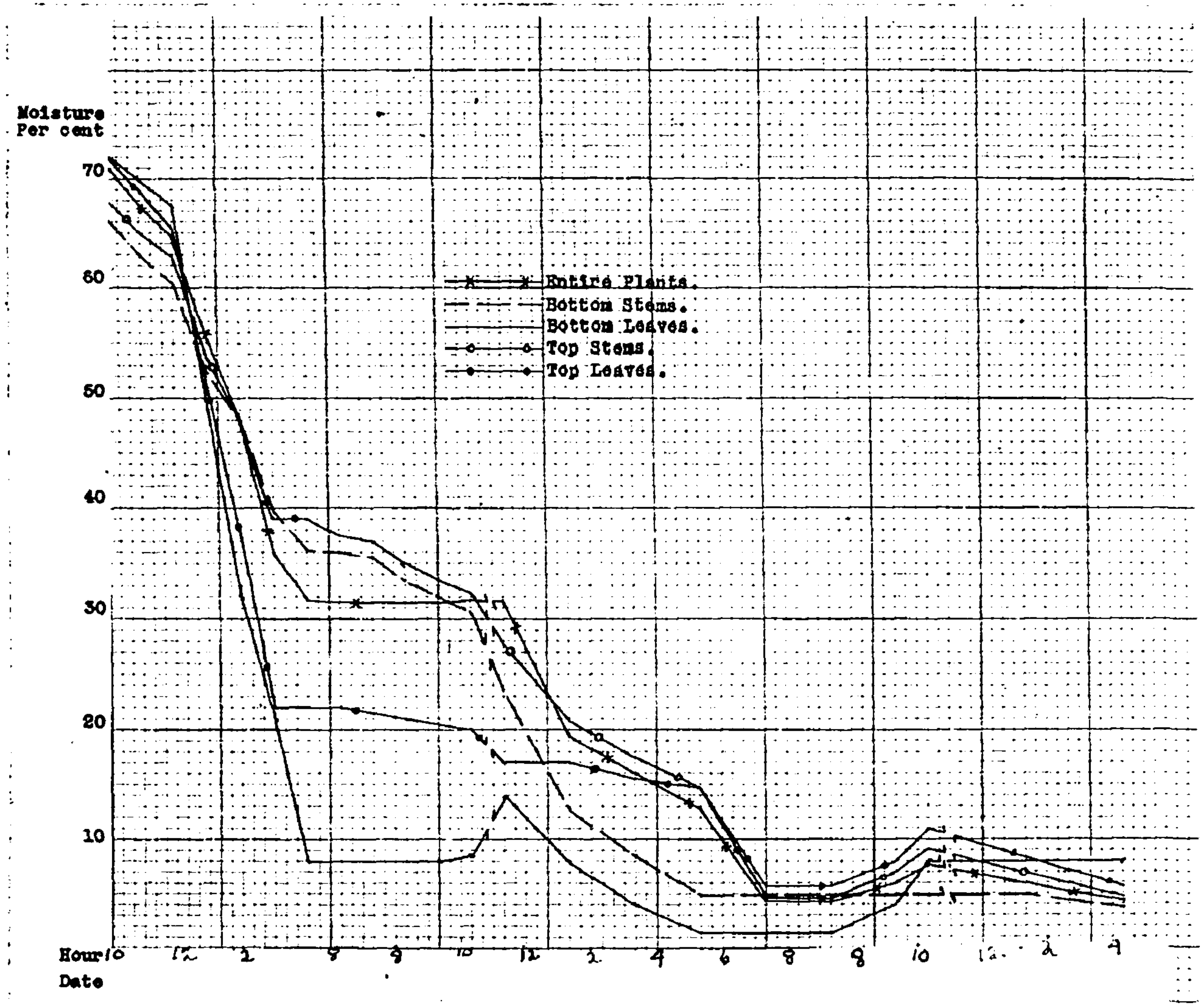

Fig. 29. The influence of the presence of the leaves on the rate of loss of moisture from the stems of alfalfa curing in the shade. 1930.

during the time that greatest loss in moisture occurred. The experiment indicates a more rapid loss in moisture in the trays containing the bottom leaves, followed in order by the top leaves, top stems and bottom stems and then the whole plant. The whole plant lost moisture at a decidedly slower rate than the various portions of the plant. This condition held true until all portions were practically air dry. After the air dry condition was reached fluctuations occurred which are not believed to have a bearing on the problem. They are more likely to be due to slight errors in weighing or to differences in absorption of moisture during the night.

With the plants cured in the shade, the trays containing the various portions of the plant dried out in the following order: bottom leaves, top leaves, whole plant, bottom stems and last top stems. The top stems lose water more rapidly than the entire plant early in the test then for a short period the whole plant loses moisture more rapidly after which the two are about equal.

If the leaves were a vital factor in the extraction of the water from the stems one would expect the whole plant to be consistently drier not just than the stems alone but drier than the stems averaged with the still drier leaves, which had been separated from these stems.

The fact that stems without their leaves are as dry as the whole plant indicates that the leaves had very little to do with the loss of moisture from alfalfa stems under the conditions of these experiments. The bottom stems dried out slightly faster than the whole plant after the plants were reduced to 30 per cent moisture.

There is no evidence in either of these tests to support the view that the presence of the leaves hastens the loss of moisture from the stems. The experiment should be repeated with a still lower evaporating environment. The whole plants in the shade experiment cured faster than the stems in the early part of the test. This tendency may be increased under still less favorable conditions for evaporation and for this reason it would be desirable to repeat the experiments with various sections of the plants with and without leaves under conditions of lower temperatures and higher relative humidity. In so far as the methods of curing hay in the field are concerned, all of the evidence presented here indicates that the leaf does not materially aid in the drying of the stem of the plant.

The Stomatal Behavior of the Leaves of Alfalfa During the Curing Process.

It was thought that something of the function of the leaf in curing might be gained from a study of the behavior of the stomata while the plant was curing. An attempt was made to study the condition of the opening of the stomata in the field by the use of a water screen on the microscope to prevent the burning of the leaf. An apparatus was made which permitted observation of the leaf without burning, but only after considerable time could a stomate be recognized in the mass of the leaf. This method was discarded in favor of Lloyd's (42) method in which a small section of the epidermis is stripped from the leaf and the stomata fixed by plunging the stripped portion into absolute alcohol.

A large number of individual plants were cut and the stomatal observations made at intervals during the drying process. Some observations were made in the sun and some in the shade. Only one observation was made on each leaf as it was observed that the second section made from a leaf showed the stomata either closed or practically so. This was credited to the effect of handling. The mature leaves were used for the sampling and in the study of individual plants there were not enough leaves to follow the curing process to completion.

In general, it was noted that the stomata when partially open on the living plant, closed in a very short time when the plant was cut. There was some variation in individual plants in the time of closing, and the different leaves of the same plant also varied. In one case, all of the stomata on the sections observed were closed in twenty minutes after the plant was cut and in another the majority were closed in 15 minutes, but at no time were the stomata uniform in degree of opening. The opening of the stomata, after they had closed following cutting, was not definite as to time. The behavior of the stomata of two individual plants, somewhat typical of those observed, is given below.

Plant A. The stomates were wide open at 9 A. M. on the growing plant in the field. The day was warm, with a moderately low relative humidity. Ten minutes after cutting most of the stomata were partially closed, and 15 minutes after cutting most of the stomata were closed; 20 minutes after cutting, practically all stomata were closed. This condition continued with observations every 5 minutes up until 70 minutes after cutting. At this time it was observed that a few stomates showed a slight degree of opening. The number of partially opened stomates increased slowly up until 120 minutes after cutting.

At this time the majority of the stomata were partially opened and a few were classed as one-half open. No striking changes were observed from following observations. A rather large number of stomates did not open at all after having once closed.

Plant B. Plant B was cut on a cloudy day with high relative humidity. This plant varied from the above in that all of the stomata did not close after the plant was cut. The stomates closed slightly slower than in the case of Plant A. The opening, after having closed once, was likewise somewhat delayed. Some of the stomates on this plant opened wide, but fully a third did not show any opening at all, while the majority were about one-fourth open.

To study the relation between the moisture content of the plants and the condition of the stomatic opening two trays of plants were used, one of which was weighed at intervals to arrive at the moisture content, the other served as a source of material for stomatal study. The first study was made on July 7 and the observations repeated on the 8th. At the period when stomatal condition is given at least five sections were observed and, in general, each estimate of the degree of opening is based on observations of 25 or more stomates. "One-half" or "one-fourth" open means that the majority of the individual stomata were open to the degree mentioned but does not mean that one-half or one-fourth of the stomates were fully open.

The study on the stomatal movement indicates a prompt closing of the stomata after the plant is cut. The closing is practically complete in 15 or 20 minutes after the plant is cut. The behavior of the stomata from this point on, during the curing process, is somewhat irregular and uncertain. The majority of the stomata seemed to open slightly, a few one-half open.

The stomata were first observed to be partially open when the average moisture content of the drying hay was 55 per cent. The leaf would be much lower in moisture content than the average of the hay. The stomata on the stems were observed to be open before cutting but were closed within one hour after the cutting of the plants.

The study of stomatal behavior is not complete. The indications from these observations are sufficient for use in making applications to the field curing of hay. The extreme variability of the plants and of the individual leaves of the same plant call for an extended investigation with careful observance of other factors which may influence the stomata, if the exact behavior

Table XXXII.

The relation between the moisture content of alfalfa plants exposed to the sun and the degree of stomatal opening.

	July 7, 1930		July 8, 1930	
Hour	Moisture of hay Per cent	Condition of Stomata	Moisture of hay Per cent	Condition of Stomata
8 A. M.	75.6	¾ open	74.2	2/3 open
8:05	--	---	--	½ open
8:10	--	---	--	¼ stomata closed
8:15	--	---	--	practically all closed
8:20	--	All closed	--	---
8:30	--	---	--	---
9:00	68.2	Practically closed	--	---
10:00	--	Few Slightly open	69.4	Few slightly open
11:00	56.4	¼ slightly open	62.0	1/3 slightly open
1 P. M.	48.4	Majority slightly open	56.3	½ about ¼ open
3 P. M.	44.2	No change	50.1	No further opening

of the stomata is to be known. A more careful study of the moisture content of the leaf as it influences stomatic opening should be made. The influence of shade, such as occurs in the windrowed hay in the field, on the opening of the stomata, also the influence of the degree of opening of the stomata on the moisture content of the hay in the field should be studied.

Discussion.

The determination of the moisture content of the alfalfa plant at regular intervals throughout the day would indicate a gradual, though slight decrease in moisture from the early forenoon until 11 A. M., then a slight rise followed by a further decrease, reaching the low point for the day about 2 P. M., after which there is a rise during the evening. The fact that during the day there is an accumulation of newly formed carbohydrate material may in part account for this apparent loss of moisture at 2 in the afternoon since with the increase in dry matter the water per cent would be less even though there was no significant drying of the plant. The temporary check in the lowering of the moisture content at 11 A. M. may be due to the closing of the stomates and consequent check in water loss between 11 A. M. and 1 P.M.

The rather limited changes in the moisture content of alfalfa throughout the day certainly would not justify cutting in the afternoon in preference to the morning, from the standpoint of rapidity in drying.

The stomates of the leaves apparently close promptly when the plant is cut and begin to open irregularly when the plant is about one-fourth cured. The stomates of the stems and leaves permit a rapid rate of drying even if practically closed. The first hour after cutting, even with the stomates closed, the leaves lost more water than at any other period. There does not seem to be any observable stimulation in the rate of drying of the plant as the stomates open.

In Experiment A it was shown conclusively that hay thrown into a windrow immediately dries more slowly than hay left in the swath, the difference between the two methods being greater in good than in poor curing weather. The idea often expressed that windrow curing maintains the leaf in a protected living condition is perhaps true. A study of the cells of the plant indicated that life remained longest in the plant with the greater moisture content. The living cells of the leaf were supposed to pass off the water from the stems thus hastening the curing process. In developing this theory the fact that the stoma close immediately after the hay is cut was overlooked. The results of comparisons between swath and windrow, showing a much slower curing in the windrow, would tend to disprove this claim of speeding the curing of the hay; as also would all of the work reported under section 4 on leaf function. The stomates of the leaves with windrow curing might tend to remain somewhat more open than in the swath curing in view of the work reported in section 5 on stomatic movement during wilting but the variation shown is so small that any influence on the rate of curing might easily be overshadowed by other factors.

The results secured in the field curing comparisons seemed to be in accord with the observed facts brought out in the stomata and leaf studies. There were three major methods of curing which were tested under comparable conditions, swath curing, windrow curing and cock curing, with numerous combinations between the three. The number of hours (7 A. M. to 7 P. M.) required to reduce the moisture content to 30 per cent as summarized for the different methods is indicated below.

(1) Swath curing completely	17.0 hours
(2) $\frac{3}{4}$ swath cured then windrowed	14. "
(3) $\frac{1}{2}$ swath cured then windrowed	17.2 "

(4) $\frac{3}{4}$ swath curing then small cocks	17.	hours
(5) $\frac{1}{2}$ swath curing then small cocks	20.5	"
(6) $\frac{1}{4}$ swath cured then windrowed	21.	"
(7) $\frac{3}{4}$ swath curing then med. cocks	22.	"
(8) Windrowed immediately	23.	"
(9) $\frac{1}{2}$ swath curing then med. cocks	26.	"
(10) $\frac{1}{4}$ swath curing then small cocks	31.	"
(11) Small cocks immediately	51.	"
(12) $\frac{1}{4}$ swath curing then med. cocks	56.	"
(13) Medium cocks immediately	92.	"

These results show that from first to last the more the material is piled together the longer the time required for curing. The hay in the swath cured first and when cured in other ways the longer the hay was left in the swath the shorter the period required to get it ready for storage. Removing hay from windrow to cock resulted in a delay in the curing process. Hay allowed to remain in the swath until one-half or three-fourths cured and then placed in small cocks reached a cured stage before hay windrowed at once reaches the same stage. The windrow cured hay is usually drying faster than hay in the cock but cannot overcome the advantage given the cocked hay by the early, rapid curing in the swath.

Hay has been shown to be of better color when cured in the windrow than in the swath. The ranking of the methods of curing on quality, or color of the hay produced, seems to be almost the reverse of the rank in time required to cure the hay. The cocked hays which did not heat were better from the standpoint of color than either windrow cured or swath cured hay. The exposure of the hay to the sun, particularly after an exposure to a heavy dew or a light rain, tends to destroy the chlorophyll. From the standpoint of color, hay $\frac{1}{4}$ cured before windrowing was the best method next to cocking, followed closely by full windrow curing, one-half swath curing, three-fourths swath curing, and with complete curing last.

The cocked hay produced excellent color except in certain cases where heating resulted. Medium cocks, made after one-fourth swath curing, or made immediately after cutting, were inclined to heat. The small cocks suffer almost as much damage in rainy weather as windrow cured hay, while with the larger cocks the entire outside layer, three or four inches in depth, may become discolored without seriously damaging the bulk of the hay. Where hay of good quality can be produced by a combination of swath and windrow curing, cocking the hay is not to be recommended. The use of the medium sized cock after one-half swath curing produced an excellent quality of hay. If cocking was done before this time, the heating of the cock tended to destroy the color.

While the time element is favorable for swath curing the leaf loss (Table XXVI) was found to be severe. The leaf loss was greatest in the extended swath curing; less in the windrow curing hay and least in the cocked hay.

After having studied the rates of curing of hay, the quality as influenced by method, the function of the leaf and stomata, it seems best to recommend that alfalfa hay be cured in the swath until one-fourth swath cured then windrowed without tedding and allowed to complete its curing in the windrow without turning. One-fourth swath cured hay was shown to cure out in 21 hours in comparison with 17.0 with swath curing and 23 for full windrow curing.

The appearance of the hay when one-fourth swath cured can be described rather definitely as well or completely wilted hay. The hay at this time is thoroughly limp and soft and is not appreciably damaged by raking. With further curing the leaves become crisp and break from the stems when raked. This recommendation is in line with the experimental evidence gathered in this study from the standpoint of time required to cure and from considerations of the quality of hay produced.

The recommendations and results of this study on methods of hay curing are in line with those of Kiesselbach and Anderson of Nebraska, though the difference between the various methods were not so great in this study as was the case in the Nebraska data.

II. STUDIES IN THE STORAGE OF HAY.

Historical.

The exact cause of the heating of hay is not known. Many theories have been advanced to account for the heating and "spontaneous" ignition of hay. Hildebrandt (27) and Browne (8) give an interesting review of ancient observations regarding the heating of plant material. Columella is quoted as saying, about 100 A. D. that "if hay is gathered too green it retains too much of its juice and rots on the scaffold and becomes hot and often ignites and catches fire." Pliny stated that "grass must never be stacked until it is quite dry or a kind of vapor will be seen arising from the rack in the morning, and as soon as the sun is up it will ignite to a certainty and so be consumed."

Ranke (64) advocates the pyrophoric carbon theory. This theory is based on the fact that materials in the pyrophoric condition are capable of very rapid oxidation and that such materials condense enormous volumes of gases within their pores and on their surface. Upon the simultaneous condensation of oxygen of the air and of inflammable gases, ignition occurs. He believed that a temperature of 300°C. was necessary in order to transform the material into pyrophoric carbon. Ranke demonstrated the capacity of pyrophoric carbon to ignite spontaneously in the air if it had in it the inflammable substances produced while transformation to the pyrophoric condition was in progress.

Cohn (14) demonstrated two periods in heat generation in barley. The first heating, which tended to stop at about 40 degrees C. he credited to the respiration of the living plant cells. After the first heating, a second period of heat evolution carried the temperature to about 65 C. This second heating period he credited to the development of thermophilic microorganisms.

Miehe (53) demonstrated the heating of hay when inoculated with specific bacteria and fungi. No heating was observed in sterile hay. Miehe suggested the possibility of low temperature carbonization leading to the formation of pyrophoric carbon. He does not believe that temperatures in excess of 80°C. will be found in any stack of hay regardless of the size unless ignition occurs. Miehe believes that the heating of hay up to 45°C. may well be due to plant respiration but at this point the heat kills the plant cells. Bacillus calfactor, he believes, develops at 40°C. and continues to develop rapidly, with a consequent rise in temperature, until it in turn is killed by the heat at about 70°C.

Boekhout and DeVries (4) believe that micro-organisms play no part in the heating of hay. They attribute the heating to purely chemical oxidation processes. They conclude that iron acts as a catalyzer in the plant material and stimulates the oxidation process. They explain the influence of the water content of the hay on the heating, by saying that water converts the pentosans and nitrogen-free extract into a state of easy oxidizability, and causes a greater production of free iron ions. This increase in the iron gives rise to a predisposition on the part of the material to undergo spontaneous heating.

Laupper (40) advanced the theory that the heating was due to pyrophoric iron. The seat of intensive heating was observed by him, to be a very limited "hot pocket". This pocket is covered by a layer of hay which has become very compact by the condensation of water and the consequent softening and dissolving of the soluble carbohydrates, pectins, gums and albuminous materials which cement the whole into an efficient insulator of the heat being generated in the pocket. Within the pocket, Laupper recognizes three danger points, the first occurring at 110°C. at which time there is a transition from the early wet to dry distillation. The second point is at 170°C., at which point he observed the explosive ignition of a mixture of ammonium nitrate and hay carbon. The third danger point is at 280°C., the point at which iron becomes pyrophoric.

Laupper has been credited with the observation of more cases of spontaneous combustion than any other writer. He describes rather fully the "hot pocket" with its radiating smoke channels. When one of these smoke channels reaches the surface of the stack, there is an inrush of air and upon contact of the oxygen with the pyrophoric iron, ignition takes place.

Tschirch (76) advanced the enzymatic-reduction theory to account for spontaneous heating of hay. The first step in the heating process involves oxygen consumption through the action of oxydases and is stopped after a slight rise in temperature by the lack of free oxygen. The second step involves the reductases, which attack the oxygen bearing organic compounds, such as the amino acids and the polysaccharids. These reductases are most active between 50 and 70°C. He believes that the action of these reductases leads finally to an accumulation of molecular oxygen which cannot escape and leads to the explosion. He does not believe that bacteria are concerned in the heating process.

Burri (10) modifies the view of Tschirch to include heat resisting enzymes and to exclude the formation of molecular oxygen by the action of the reductases. The heating and final ignition are due to purely chemical changes.

Hildebrandt (27) believes that his experiments have shown that enzymes have very little to do with the heating and that without microorganisms heating is impossible.

Browne (8) believes that the microorganisms function as a cause of the heating only in so far as they produce unsaturated, highly unstable, intermediate fermentation products on the surfaces of the porous cellular material. The duration of these readily oxidized products depends upon the quantity of air that can gain access to the fermenting mass. In small open heaps, the intermediate products are destroyed as soon as formed and the heating ceases when the microorganisms are killed at 70 to 80°C. He believes that the heat production is caused by the oxidation of these unstable compounds at temperatures up to 150°C, or as high as is necessary for ignition. In large heaps, with the supply of oxygen limited, ignition may result, the unstable compounds persisting and the heating continuing after the organisms producing them are killed.

Truninger (75) has criticized severely the chemical technique and the results obtained by Laupper. He does not believe ammonium nitrate is formed as Laupper found nor that the temperature necessary for the forming of pyrophoric iron is reached until after ignition has taken place. In many tests Truninger ignited hay at temperatures ranging from 190°C to 226°C.

Truninger also notes, in Switzerland, a connection between the agricultural region where cattle production is highest and the occurrence of spontaneous fires. He attributes this to the liquid manure fertilization prevailing in the section. Truninger had an opportunity to measure the temperatures of many overheating stacks and found that in most cases the temperatures in the hottest parts was 85 to 90°C. One overheating stack gave a temperature reading of 180°C. After the heating had stopped this stack was cut open and a little pile of ashes found in the bottom of a hole indicating that ignition had taken place.

The cause of the heating of hay up to between 40 and 45°C. has been credited by Miehe (53), Cohn (14), Laupper (40), and Tschirch (76), to the respiration of the living cells of the plant. Hilbrig, H. (26) reports that the cells of the rye and Brome grasses were killed between 40 and 45°C. Holdefleiss (28), Laupper (40), Miehe (53) assume that microorganisms have the ability to produce comparatively high temperatures. Browne (8), Hildebrandt (27) and many others do not believe the respiration of the living plant cell raises the temperature of the material. According to Maximov (45,p.244) the work of physiologists would preclude this cause of the heating, as the cells of many plants die when the water content is reduced.

Haldane and Makgill (22) suggest that the first period of heating may be due to chemical oxidation, and that this is followed by, or aided by, molds, then by bacteria, and finally, again, a pure chemical oxidation carries the heating to the point of ignition. They believe that the important work of the microorganisms is in the formation of unsaturated fermentation products which induce an increased oxygen absorption.

Bond (5) states that hay must be mowed before the cells are dead or it will fail to sweat properly. Hay which cures out so slowly that the cells are dead when placed in the mow passes through a "cool" sweat with a heavy development of mold.

Actual, scientifically observed cases of fire in hay resulting from spontaneous combustion are not numerous.

Ranke (64) describes a case which is typical of others and indicates the preliminary stages very well. $22\frac{1}{2}$ tons of second-cutting hay apparently well cured was piled in one pile in a large barn on August 10. On October 17 and 18 a burnt odor was noticed which became so strong on the 19th that observers determined to remove the hay. In the upper part of the mow the normal green hay was sweating and drops of water were hanging to the stems of the hay. When a layer had been taken from the top, the hay underneath was dry and very hot. At a depth of five feet, several sparks were seen in the hay and on the wagon which was used to haul the hay away. This hay was a deep brown color. From this point, every forkful of hay began to glow as soon as removed and the stack was continually being drenched with water. Hay hauled and spread out on the grass outside re-ignited repeatedly. Gas was evolved to such an extent that the workmen could work only one or two minutes and then would rush out gasping for air. The mass of burnt hay resembled carbon except that its original structure was retained.

James, L. J., et al (32) have described a case of spontaneous ignition in a heap of stable manure at Arlington Farm, Va. The actual heating centers were within six inches of the outside. The temperature at or near the heating center was found to be 167°C., while at a distance of three inches the temperature was only 80°C. Some of the hay in one of the heating centers was spread out on the ground. The straw was hot and steaming. In about one minute the steam had changed to smoke and in three minutes the material began to glow a fiery red.

James and Price (33) describe the conditions under which a hay barn burned from spontaneous ignition. The barn, containing 50 tons of meadow and alfalfa hay was in the flood district in Vermont. The flood waters covered the hay to a depth of 17 feet. On the 5th of November, 24 hours after the waters receded, the hay was steaming, and the barn burned on November 7, or about two days after the flood waters receded. The barn and hay stood in three feet of water when the fire broke out. The air temperatures were low during the period and some rain fell every day.

Truninger (75) reports a case of spontaneous ignition which destroyed a stack of supposedly well-cured hay 10 days after the stack was made.

Some experimental work has been reported concerning the influence of the moisture content of the hay at the time of stacking on the heating developed in the stack and the changes in the appearance and quality of the hay.

Among the earlier attempts to measure the heating in hay with a known moisture content is the work of Miehe (53). A stack of hay with 31.4 per cent moisture was made. The stack was tramped as it was being built and tubes were placed in the side and plugged so that thermometers could be shoved into the center of the stack. A maximum thermometer was placed in the center of the stack and left throughout the test.

The daily maximum temperature in the center of the stack rose from 24 degrees at the start to 68.5°C. on the 8th day then fell to 54.8 on the 14th, rose slowly again reaching 61°C. on the 18th day then fell almost regularly to 33.8° on the 43rd day. The outside temperature varied from 17 to 28 degrees C. during this time. Miehe describes the stack on the second day as being strongly steaming with the outer part very moist,- the stems of the plants covered with drops of water. Miehe states that the bulking of hay with 36 per cent of moisture may result in normal spontaneous heating. With a lower moisture content, the heating will be less. Hay with 30 per cent of moisture is thought to be about right for the development of brown hay accompanied by a normal course of spontaneous heating.

Browne (8) suggests that the range of the moisture content at which spontaneous ignition can take place is probably confined to somewhat narrow limits. If the moisture content is too high the heat is used up in the evaporation of the water, if too low, the course of the final rapid heat production is retarded.

James, et al (32) found the moisture content in a heap of stable manure to be 3.7 per cent adjacent to the glowing area and 30.2 per cent two feet away in a badly charred area, while the uncharred material on top of the stack has 66 per cent of moisture.

McClure (52) states that the moisture content of hay considered field cured, varied from 15.1 to 33.1 per cent.

Vinall and McKee (77) report the moisture of field cured alfalfa as ranging from 4.6 per cent to 30 per cent.

Truninger (75,p.329) sampled hay as farmers considered it cured and found the moisture to vary from 20 to 39 per cent. He studied the course of the heating in several stacks of hay. The maximum temperature in a normal hay stack in the upper layers was 33°C., in the lower portion of the stack it was 48°C. In a stack which formed light brown hay, the temperature rose to 40°C. in the upper layers and 52°C. in the lower portion. Truninger, also, stacked hay with 40.1 per cent moisture which was unevenly cured and had been exposed to rain, in a stack 4.8 meters high and 2.8 meters in diameter. The temperature rose from 30°C. on September 3 to 86°C. eight days later and remained above 80°C. until November 5 at which time the temperature fell. The stack was cut open and the hay described in successive layers. (a) The outer 10 cm. layer was yellowish bleached, stemmy hay. (b) the second 10 cm. layer was normal, yellow-green hay. (c) The next 7 cm. was grayish-green and moldy. (d) the next 10 cm. was brownish yellow and heavily molded. (e) the next 10 cm. was a white, intensively molded, sharply marked zone. (f) The brown hay zone extended for 20 cm. inside this. There was very little mold present. (g) The remainder of the hay was strongly overfermented and of a brownish black color. The overheated material lost 19.7 per cent of its nitrogen-free extract, gained 13,5 per cent in raw fiber, lost 6.5 per cent of its digestible protein and gained slightly in crude protein.

Truninger summarizes his work and his suggestions on the care of hay in storage for each of the following degrees of heating. (1) In normal well-cured hay the rise in temperature may be expected to stop at or below 55°C. (2) Light over-heating, with brown hay formation, occurs if hay heats to from 55 to 65°C. but does not go above this point. When this heating is in progress, holes should be bored into the heating areas with a hay-stack borer. (3) Heavy over-heating: the temperature may range from 65 to 85°C., there is a large nutrient loss, the hay is a dark brown and has suffered a severe loss in digestibility. Sections about one meter square should be cut out of the hay exposing heating centers. (4) Very heavy over-heating. Carbonization is taking place at the temperatures between 85°C and 95°C. This results in a total loss of the feeding value of the hay. There is danger of spontaneous ignition. The stack should be covered with wet blankets, and the heating centers should be flooded before the hay is exposed to the air. After it is flooded, cut out the heating centers. (5) Beyond 95°C. fire danger is imminent. The fire fighting equipment should be in readiness, the heating center flooded and the good hay removed.

Grasemann (21) states that the protein of hay is rendered indigestible in proportion to the degree of over-heating. Digestibility tests were made on normal hay, medium overheated hay, and heavily overheated hay. The medium overheated hay was good brown hay. The heavily overheated hay was dark brown and had a stifling odor. The digestibility was determined by chemical extraction. In normal hay, 73 8 per cent of the protein was digestible while only 45.1 per cent was digestible in the medium and 13.2 per cent in the heavily overheated hay. Grasemann believed the "starch-value" of the hay was decreased by half.

In a feeding test in which normal hay, medium brown hay and heavily over-heated dark brown hay was fed to dairy animals, the ranking of the hays in digestibility of the protein was confirmed by production records. The belief of feeders that the brown hay is just as good as green hay, Grasemann believes, is due to the fact that the animals eat more of the brown hay.

Boekhout and DeVries (4) report a loss in protein of 1.2 per cent; pentoses, 15.8 per cent; and nitrogen-free extract 22.3 per cent, when hay was heated from 95 to 100°C.

Bond (5) states that the losses in the making of hay vary from 10 to 20 per cent and that in overheating of the hay in storage, losses may amount to 30 per cent of the valuable materials of the hay.

Bethke and Kick (3) report that alfalfa exposed to the sun showed a marked decrease in vitamin-A. Experimental work at the Kansas Station (11) showed that green hay was more efficient from the standpoint of milk and butter fat production when fed to dairy animals than brown hay. The brown hay used in the experiment was dark brown and somewhat crisp.

Salting hay at the rate of 5 to 15 pounds to the ton of hay has been advised quite generally in this country. Hartwig (23) states that a survey showed that between 60 and 65 per cent of the farmers questioned used salt on at least some of their hay. He also reports an experiment in which hay ranging in moisture content between 20 and 40 per cent was salted with no beneficial effects when compared with some of the same hay stored without salting. Hartwig advises the use of 15 to 18 pounds of salt per ton of hay.

Truninger (75) states that the addition of one per cent of salt to hay has but little value. If sufficient salt is placed on the hay to make a crust, it might check the development of fermentation organisms. However, he recommends the use of one per cent of salt on insufficiently dried hay.

Hildebrandt (27) advises the use of stock salt on improperly cured hay. In one test, the moistened hay heated to $63\frac{1}{2}^{\circ}C$ without salt and the heating stopped at $43^{\circ}C$. where 1.5 per cent salt had been used.

Experimental.

The studies in storage of hay were planned to secure specific information on the heating of hay in storage, and to determine the influence of the moisture content of the hay and the use of salt on the intensity of the heating.

Methods. The hay used for storage was from an 8-acre field on the W. F. Templeton farm. This field was seeded for the hay curing and storage experiments. By the use of the weighing device used in the rate of curing tests, it was possible to obtain hay with a known moisture content when it was placed in the mow. Shrinkage samples were taken at the time the hay was cut. In the baling tests a similar procedure was followed.

In the mowing studies, 6 experimental mows were used. These were in two sections of three mows each, mounted on sled runners to facilitate mowing when necessary. The mows were five feet six inches square and five feet deep, and built of tight fitting ship-lap. In order to make the sides as air tight as possible the outside was covered with heavy asphalt roofing paper and the inside was lined with ordinary black building paper. One-half of the roof was hinged and could be braced open while filling the mows. The hay was well tramped as it was put in the mow. Toward the top of the mow, pressure was applied by means of an automobile jack. It was not possible even with this pressure to put in the mow quite as much hay as should have been used to make the density of the cured hay equal to that found in a large mow.

In the baling tests, the bales were of standard size. The baler used was mounted on a tractor and equipped with a hay loader. This baler could be driven alongside a windrow, picking up and baling the hay when the moisture content was reduced to the amount desired for the test. Shrinkage samples were taken at the time of baling.

Boxes, thermos jugs and large insulated galvanized iron cans were used for other studies on the storage of hay. These are described when the results of the tests are given. Temperature readings in the small containers and in some of the bales were made with ordinary Centigrade thermometers. In the study of the temperatures in the mows a portable potentiometer and copper-constantine thermocouples were used. The location of the thermocouples is indicated in each experiment.

The carbon dioxide and oxygen gas present in the mow at verious times was determined. The Hayes gas analyzer was used for this work. In some of the earlier tests samples were taken through glass rods thrust into the mow; in the later tests these were replaced by copper tubes.

Results of Experiments.

Evidence on the factors involved in the storage of hay has been secured from four general types of experiments: A. Experiments to determine whether or not there are living plant cells in cured hay; B. Studies on the heating of alfalfa in small containers; C. Studies on the storage of hay in experimental mows; and D. Studies on the baling of alfalfa from the field.

A. Experiments to determine whether or not there are living plant cells in cured hay.

The assumption of Miehe (53) and others that the plant cells are alive in curing hay and that the first heating that occurs in the stored material is due to the respiration of the living plant cells has been questioned. The suggestion has been made by Maximov (45,p. 374) and others that plant cells of vegetative tissue die when deprived of much of their moisture. In order to test for the presence of life in the cell, plants and portions of plants were allowed to dry in the sun and in the shade. Moisture determinations were made at intervals and sections of the stems were cut under water to test for the recovery of the turgidity of leaf and stem. This recovery of turgidity would demonstrate the presence of life in the plant cells.

In estimating recovery the percentage basis has been used. The percentage of the number of stems or leaves tested that show a partial or complete recovery of turgidity is given for each test. The recovery of the leaves is tested with the leaves attached to the stems. The plants tested were drying in the sun in one case and in the shade in another. The results of the experiment on sun cured plants is given in Table XXXIII.

It will be noted that the leaf and stem regain their turgidity when the moisture content is reduced far below that of field cured hay. The leaves recovered when the moisture content had been reduced to 9.3 per cent in the case of the younger leaves of the top of the plant and 14 per cent for the lower, older leaves. Stems recovered after being dried to 10 per cent moisture or less. The younger upper stems and leaves show greater recovery than the lower older ones.

Table XXXIII.

The relation of the presence of living cells to the moisture content of the alfalfa plant as shown by the recovery of turgidity when the partially sun-dried portion is placed in contact with water in a saturated atmosphere. 1930.

Portion of Plant			Upper Leaves		Upper Stems		Lower Leaves		Lower Stems	
			Moisture	Recovery	Moisture	Recovery	Moisture	Recovery	Moisture	Recovery
Month	Day	Hour	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
July	8	10	71	100	68	100	72.3	100	66.2	100
		12	41.0	100	56.9	100	24.4	100	46.0	100
		1	23.8	100	26.8	100	14.6	100	27.6	100
		2:30	9.3	75	12.1	100	14.	50	10.1	100
		3:15	6.0	35	10.1	100	4.6	4.	10.1	100
		4:15	6.0	20	7.5	100	1.8	0	10.1	100
		5:30	6.0	0	7.5	100	1.8	0	10.1	100
		9:00	13.3	12	12.7	100	1.8	0	10.1	62.5
July	9	8:00	13.3	6	12.7	72	1.8	0	10.1	21.0
		10:00	10.2	16	1.8	50.0	1.8	0	1.1	16.0
		2:30	6.0	2	1.8	16.0	0.0	0	0.4	0
		4:00	6.0	0	0.0	0	1.8	0	0.4	0
		6:00	6.0	0	1.8	0	1.8	0	0.4	0
		9:00	6.0	0	1.8	0	4.6	0	4.23	0

The results of the experiment on shade cured plants is given in Table XXXIV. The element of time seems to enter in to influence recovery. Apparently a reduced moisture content over a period of time tends to kill the cells as well as a lower moisture content. The upper leaves apparently were largely dead when the moisture content was reduced to 20.1 per cent and while the lower leaves recovered with 8 per cent, the upper leaves showed some slight recovery with 5.6 per cent moisture. The upper stems recovered with as low as 2 per cent of moisture and the lower stems with 4.8 per cent. This certainly shows that the cured hay plant normally has living cells in leaves and stems.

Studies on the Heating of Alfalfa in Small Containers.

In the study of the storage of hay, various containers have been used in an effort to approximate some of the conditions found in mowed hay on a small scale. Small, one-gallon thermos jugs were used in several tests of heating. These jugs prevented the radiation of a good portion of the heat. However, the small mouth prevented the proper packing of the material so that in all cases heating was limited. Sufficient information was gained from their use, however, to justify the statement that

Table XXXIV.

The relation of the presence of living cells to the moisture content of the alfalfa plant as shown by the recovery of turgidity when the partially shade-dried portion is placed in contact with water in a saturated atmosphere. 1930.

Portion of Plant			Upper Leaves		Upper Stems		Lower Leaves		Lower Stems	
Month	Day	Hour	Moisture Per cent	Recovery Per cent	Moisture Per cent	Recovery Per cent	Moisture Per cent	Recovery Per cent	Moisture Per cent	Recovery Per cent
July	8	10:00	72.2	100	68.0	100	72.3	100	66.2	100
		12:00	65.4	100	62.8	100	67.5	100	60.1	100
		1:00	49.7	100	53.8	100	49.8	100	52.8	100
		2:30	28.8	100	44.7	100	21.1	100	45.2	100
		3:15	22.1	100	39.1	100	21.1	100	39.9	100
		4:14	22.1	100	39.1	100	8.0	100	36.2	100
		5:30	22.1	90	37.3	100	8.0	25	36.2	100
		9:00	20.1	16	32.3	100	8.0	0	30.5	100
July	9	8:00	16.9	4.0	27.6	100	13.8	20	23.6	100
		10:00	16.9	6.0	20.8	100	8.0	0	12.8	100
		2:30	14.7	10.0	14.6	100	1.4	20	4.8	100
		4:00	5.6	4.0	4.6	100	1.4	0	4.8	100
		6:00	5.6	3.0	4.6	100	1.4	0	4.8	100
		9:00	11.0	2.0	9.1	100	8.0	0	4.8	100

conditions other than moisture content may materially influence the heating of the material, particularly with hays of the higher moisture contents. Typical of the results of several tests are those given in Table XXXV.

The hay used in these jars was good, green hay chopped into about one-inch lengths and water added to give the moisture content shown. The hay lost its green color in all of the jars. At the end of the test, it was grayish brown in color, rather heavily molded. These results are somewhat typical of results secured where no means of gas exchange is provided. The heating, regardless of the moisture content of the material, is low and usually the green color of the hay is destroyed by an accumulation of carbon dioxide even though the temperature may not vary more than 5 degrees from air temperature.

In another test somewhat better results were obtained by using containers which consisted of a four gallon can placed in a second galvanized iron can large enough to hold the smaller can surrounded by a four inch layer of sawdust. Each can was equipped with a tight fitting lid through which openings were made for the insertion of a thermometer and of a tube through which samples of gas could be drawn. The space between the

Table XXXV.

The influence on the temperature developed in the mass of adding different amounts of moisture to dry hay. 1930.

Moisture Content:		Jar No. I: 53.3	Jar No. II: 47.2	Jar No. III: 39.3	Jar No. IV 28.6
Month	Day	C°	C°	C°	C°
March	31	31.0	30.5	30.0	29.5
April	1	31.0	32.0	29.5	29.0
	2	30.5	31.5	29.5	29.0
	3	30.0	31.0	30.0	29.0
	4	25.5	29.0	26.5	25.5
	5	30.5	32.5	29.5	29.5
	6	31.5	34.5	30.0	29.5
	7	31.0	33.0	29.5	29.5
	8	30.0	31.0	28.0	26.0
	9	32.0	32.0	31.0	28.0
	10	29.0	30.0	30.0	29.0
	11	30.0	31.5	30.0	29.0
	12	28.0	29.0	28.0	28.0
	13	26.0	27.0	26.0	26.0
	14	26.0	26.0	25.0	26.0
	15	28.0	29.0	28.0	29.0

two lids was filled with cotton. Four of these containers were filled with chopped hay to which water had been added to bring the hay to the desired moisture content. The observed temperatures and the carbon dioxide present in these containers are given in Table XXXVI. The hay in the first three of the containers was brown in color while that in IV was slightly green. There seems to be a direct relation between the moisture content, the heating and the carbon dioxide produced in artificially moistened hay. The material in container No. I had heated to 55°C. by the fifth day, while on the third day it showed 8 per cent of carbon dioxide. The carbon dioxide determination was secured by drawing samples of the gas from about four inches above the bottom of the container by means of a bent glass tube which extended down the side of the container, across the bottom, and ended about four inches above the bottom. Gas was drawn in through the top to replace the sample drawn out. Hay with 42.3 per cent moisture and with 35.4 per cent moisture heated almost as much as hay with 45.6 per cent but the carbon dioxide content was not so high. Hay with 30.4 per cent moisture did not produce excessive amounts of carbon dioxide and did not reach as high temperatures as were noted in the other three containers.

The galvanized iron containers were used for a

Table XXXVI.

The influence on the temperature developed and the carbon dioxide present in the mass of adding different amounts of moisture to dry hay. 1930.

Moisture Content:		Container I: 45.6		Container II: 42.3		Container III: 35.4		Container IV: 30.4	
Month	Day	C°	CO_2	C°	CO_2	C°	CO_2	C°	CO_2
May	1	51	4.0	50	2.5	47	2.3	42	0.5
	3	53	8.0	50	1.0	48	1.0	47	0.5
	5	55		55		54		47	
	7	55	3.0	55	1.0	54	0.5	48	0.5
	9	52	1.5	52	0.7	50	0.5	48	0.5
	11	50		49		48		48	
	13	48		45		45		45	
	15	48		48		48		45	
	17	47		45		43		43	
	19	44		44		44		43	
	21	41		41		40		39	
	23	40		39		39		39	

second test in which freshly cured alfalfa hay was stored. Containers No. II and III were filled with hay of the same moisture content but salt was added to the hay in No. III at a rate of 1 per cent. The results of this test are given in Table XXXVII. In containers No. I and II the highest carbon dioxide content and the highest temperatures were noted on the fifth day. In most of the studies the greatest amount of the heating has occurred on about the fifth day after the mowing of the hay. The carbon dioxide content of container No. I was 10.3 per cent which is the highest observed in any test of heating hay.

A rather striking effect of the use of salt is to be seen in this test. Container No. III was salted and while the heating in this container was but slightly less than that in No. II which contained hay with the same moisture content yet the carbon dioxide content was substantially less in the salted hay. The hay in containers No I and II was brown at the end of the test while that in No. III and IV was green in color.

A system of hay curing has been reported from England in which the hay was stacked green around a central core and after considerable heat had been generated unheated air was blown through the hay, the air

Table XXXVII.

The influence of the moisture content and of the use of salt on the temperature developed and carbon dioxide present in field-cured hay stored in tight containers. 1930.

Moisture Per Cent:		Container I: 44.3		Container II: 35.6		Container III: 35.6 (1)		Container IV: 27.3		Max. Air
Month	Day	C°	CO_2	C°	CO_2	C°	CO_2	C°	CO_2	Tem.C°
June	15	35	1.1	33	1.1	34	0.3	32	0.5	27
	16	44		42		40		37		24
	17	46	3.2	46	2.1	48	0.5	36	0.5	21
	18	49		48		48		35		25
	19	55	10.3	50	4.2	46	0.8	34	0.5	25
	20	54		48		45		33		29
	21	52	8.2	48	2.2	47	0.3	34	0.4	34
	22	50		46		48		34		35
	23	46	4.1	40	1.3	45	0.5	36	0.7	35
	26	47		38		41		35		28
	28	45	1.0	37	0.7	43	0.7	35	0.8	31
July	1	40		34		37		33		25
	3	42	1.2	36	1.1	36	0.5	33	0.4	27
	6	42		36		33		33		33
	8	40		39		34		33		33

(1) salted

carrying away the excess water. In order to secure information on the possibilities of a method employing similar principles unheated air was blown through heating chopped alfalfa in 1927 with the conditions as described: The hay was chopped into one-half inch lengths and placed in boxes 4' square and 4' deep, each of which was provided with a raised bottom made of hardware cloth and an opening in the bottom connected with a 3" forge blower operated by a 1-h. p. electric motor. A blast of air was blown through the hay at intervals for periods of 30 minutes. Temperature measurements were made with long stemmed thermometers thrust deep into the hay.

At each time of blowing, the steam rolled out of the top of the box in a dense cloud, collecting on the top hay and on the ceiling of the room. Each time the blower was started, the temperature rose rapidly in certain areas. These heating centers were rather sharply defined and at times a distance of three inches caused a difference of as much as 20 degrees in the temperature. The material became slimy, sticky and softened. When the experiment was discontinued, the material was a rather uniform gray color with an acid odor. The moisture content at the time of filling was 58.6 per cent in

Boxes I and II and 44.3 in Box III. In spite of the heating and of the apparently large quantities of water being given off, the hay did not lose moisture at an economical rate at all. At the end of the experiment, the moisture content was 50 per cent, 52 per cent and 30.3 per cent, respectively. The course of the heating is indicated in Table XXXVIII.

A study of Table XXXVIII gives a rather striking illustration of the rapidity of heating in green material. It will be noted that after being cooled down to 24°C. by blowing cold air through the hay it heated again to 54°C. in 10 hours time. Hay that had cooled in the afternoon of one day would be hot the next morning.

Studies on the Storage of Hay in Experimental Mows.

The character of the experimental mows and the method of filling has been described under Methods. These were filled on five different dates and the temperatures determined by means of the potentiometer and thermocouples. The temperatures were read every two hours in the early part of each test and less often after the course of the heating was evident. Daily readings were made over a period of from one to two months. Where comparisons were to be made between salted and unsalted hay, two or

Table XXXVIII.

The influence of blowing air through heating hay on moisture content and on the temperatures developed. 1927.

Month	Day	Hour	Box I Temp. C°	Box I Weight 540	Box II Temp. C°	Box II Weight 555.5	Box III Temp. C°	Box III Weight 538.5
Sept.	7	9:00	52		49		52	528
		10:00	23B	526	52		23B	
Sept.	8	11:00 AM	25		24B	547	24	525
		5:30 PM	35		30		37	
		9:00	45		41		22B	515
Sept.	9	7:30 AM	52	522	41	541	32	
		9:00	22B	508	49		35	
		10:30	24		24B	530	34	
		3:00 PM	27		26		46	
		8:00	28		28		23B	
Sept.	10	8:00 AM	41	503	41		40	
		10:30	48		42		44	
		1:00 PM	54		46		46	
		3:00	24B	489	47		51	
		5:30	26		52		23B	499
Sept.	11	9:00 AM	41		40		45	
		5:00 PM	54		50		22B	
		6:00	22B		54		22	
		7:30	23		20B		22	
Sept.	12	8:00 AM	35		33		32	
		5:30 PM	52		41		45	
		8:00	23B	455	46		52	
Sept.	13	8:00 AM	40		60			
		9:00	41		61		24B	475
		11:00	43		23B	525	25	
		3:30 PM	54		24		33	
Sept.	14	8:00 AM	42		38		60	
		9:30	46		30		23B	461
Sept.	15	7:30 AM	25B	441	56		36	
		1:00 PM	30		24B	473	52	

Table XXXVIII (Cont'd.)

Month	Day	Hour	Box I Temp. C°	Box I Weight 540	Box II Temp. C°	Box II Weight 555.5	Box III Temp. C°	Box III Weight 538.5
Sept.	16	9:30 AM	58		28		24B	424
Sept.	17	11:10 AM	40		60		30	
Sept.	18	9:30 AM	40		32		30	
Sept.	19	10:00 AM	50		60		20	
		1:00 PM	55		20		20	

B = Cold air blown through for one half hour; temperature at end of the blowing period.

more mows were filled with hay of the same moisture content, one of which was salted at the desired rate.

Mowing studies in 1928.

The mows were first filled on June 26, 1928. One thermocouple, located near the center was used in each mow. As the hay settled somewhat, due to the softening of the hay, additional hay was added on the top and pressed down. The temperatures developed in the mows for the duration of the experiment are given in Table XXXIX. The temperature of each mow is shown graphically in Figure 30.

A study of Table XXXIX and Figure 30 show very clearly an immediate temperary rise in temperature lasting about 2 days after which the hay cooled off for a very brief period then heated again. Mow I and II with 34 and 38 per cent moisture rose to 60°C. on the fifth day after mowing. This high temperature was held but momentarily then the hay cooled to about 44°C. Mow I maintained this temperature for 12 days after which it slowly lowered to 30°C. at the end of the test. Mow II held a temperature of 44°C. for only 6 days then cooled to about 30°C. and maintained this temperature until the end of the test. The hay in Mows I and II was found to moldy and brown at the end of the test.

Table XXXIX.

The influence of the moisture content of alfalfa hay and the addition of salt on the temperature developed in the mow. 1928.

			Mow One	Mow Two	Mow Three	Mow Four	Mow Five	Mow Six
Moisture Content			34.28	38.78	32.19	25.89	25.89	20.21
Month	Day	Hour	C°	C°	C°	C°	C°	C°
June	26	8 PM	41	40			Salted 2 per cent	
	27	8 AM	42	54				
		12 M	45	50				
		8 PM	48	52				
	28	8 AM	43	48				
		12 M	34	34				
		8 PM	33	33				
	29	8 AM	38	35				
		12 M	52	51				
		8 PM	54	54				
	30	8 AM	55	55				
		12 M	60	57				
		8 PM	59	59				
July	1	8 AM	59	63				
		12 M	65	63				
		8 PM	57	60				
	2	8 AM	50	50				
		12 M	47	52				
		8 PM	49	49		38	30	28
	3	8 AM	43	49		37	34	22
		12 M	40	43		33	29	22
		8 PM	45	48	33	35	32	28
	4	8 AM	41	45	20	29	26	18
		12 M	41	43	16	26	23	20
		8 PM	47	45	23	28	24	24
	5	8 AM	41	47	24	24	22	21
		12 M	41	45	24	26	22	20
		8 PM	41	45	25	26	22	22
	6	8 AM	46	45	26	26	20	18
		12 M	48	44	28	25	21	25
		8 PM	50	45	29	26	24	26
	7	8 AM	45	47	31	23	23	24
		12 M	45	45	32	31	23	26
		8 PM	45	46	38	30	25	27

Table XXXIX. (Cont'd.)

Moisture Content			Mow One 34.28	Mow Two 38.78	Mow Three 32.19	Mow Four 25.89	Mow Five 25.89	Mow Six 20.21
Month	Day	Hour	C°	C°	C°	C°	C°	Co
July	8	8 AM	45	48	32	35	25	23
		12 M	38	49	33	38	26	23
		8 PM	36	49	40	38	24	28
	9	8 AM	35	48	37	42	23	23
		12 M	33	46	39	43	22	24
		8 PM	31	43	39	42	22	23
	10	8 AM	31	43	30	39	22	22
		12 M	29	43	29	38	21	22
		8 PM	33	44	28	39	23	28
	11	8 AM	30	42	30	38	21	21
		12 M	32	45	27	39	22	22
		8 PM	34	45	32	39	23	25
	12	8 AM	32	44	26	39	23	20
		12 M	37	45	26	39	23	23
		8 PM	41	45	34	38	23	24
	13	8 AM	38	45	26	35	20	20
	14	8 AM	33	40	21	29	18	18
	15	8 AM	29	38	20	29	18	15
	16	8 AM	34	33	19	28	18	18
	17	8 AM	31	35	21	26	17	16
	18	8 AM	32	32	27	35	20	21
	19	8 AM	36	35	22	35	22	24
	20	8 AM	32	37	26	31	22	25
	21	8 AM	27	32	18	26	19	16
	22	8 AM	29	32	19	27	21	23
	23	8 AM	32	37	13	28	16	14
	24	8 AM	20	28	13	23	17	14
	25	8 AM	26	33	13	22	13	9
	26	8 AM	20	28	16	18	16	10
	27	8 AM	25	33	18	20	17	17
	28	8 PM	20	25	13	17	9	10
	30	8 PM	21	21	20	19	20	16
Aug.	1	8 AM	22	24	14	15	17	16
	7	8 AM	24	30	20	20	20	20

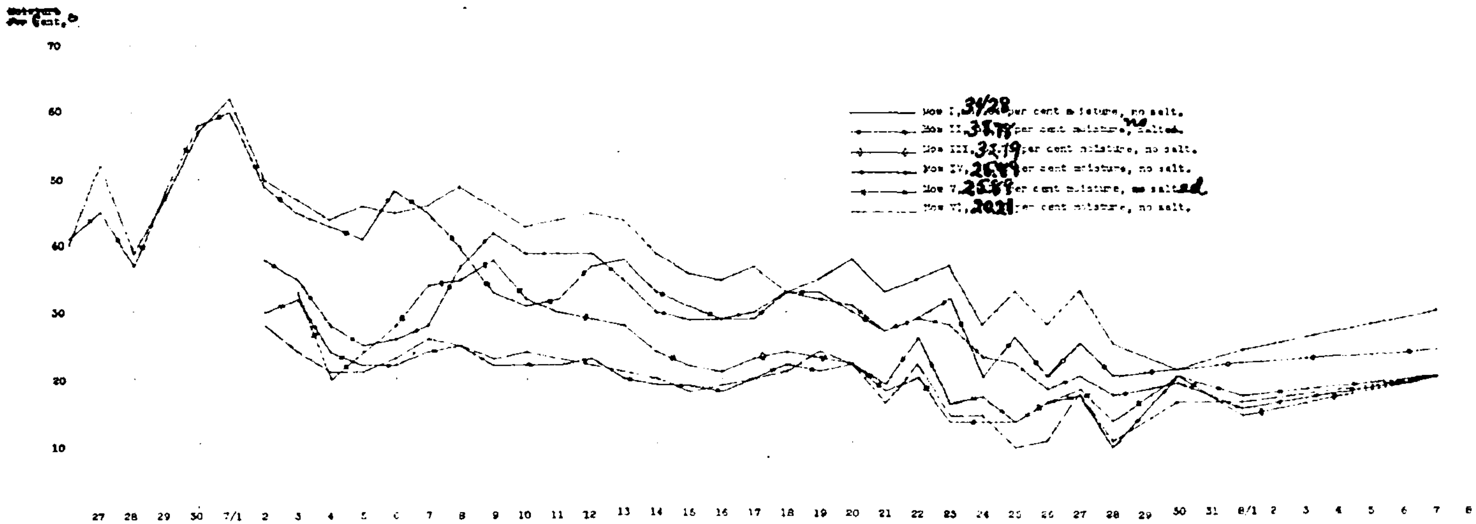

Fig. 30. A study of storage conditions in mows filled with hay of known moisture content and the influence of the moisture content of the hay and of salt on the temperature developed in the mow. 1928.

Mow III with 33 per cent moisture was heating at the time of the first measurement, from 30°C. the temperature dropped to 20°C. in one day then quickly rose to the highest point of 37°C. on the 6th day after mowing. Mow III cooled gradually to around 20°C. The hay in Mow III had an olive green color and was good hay.

Mow IV and V each with 25.89 per cent moisture gave the most striking difference in favor of salting hay that was obtained in any of the tests. Mow V was salted with 2 per cent stock salt at the time the hay was placed in the mow. The temperatures of both mows was high at the time of the first measurement but dropped on the second day to around 23°C. Starting on the fifth day the temperature in the unsalted hay rose rapidly to 42°C. while the temperature in the salted hay was 22°C. The salted hay did not heat appreciably during the entire test while the temperature of the unsalted hay was above 30°C. for 13 days. The hay in Mow IV was brown and moldy at the end of the test while the hay in Mow V had some good green color.

Mow VI filled with hay with 20.2 per cent moisture heated slightly as it was mowed then cooled and remained cool throughout the test. The hay was good green hay at the end of the test.

In the late fall of 1928, a first years growth of sweet clover was cut and stored in the experimental mows. Air temperatures were quite low during the period of the experiment. Mow I and II were filled with uncured clover having a moisture content of 55.2 per cent. Mow II was salted at the rate of 1 per cent while no salt was used in Mow I. Mow III was filled with well cured hay. Mow IV, V and VI were filled with hay having a moisture content of 19.3 per cent. Mow V was salted at the rate of $\frac{1}{2}$ per cent and mow VI at the rate of 1 per cent. The temperatures for the period of the experiment are given in Table XL.

A study of the data in Table XL shows that the heating of the hay was not important except in Mow I and II in which hay with 55.2 per cent of moisture was stored. Mow I was not salted while Mow II had 1 per cent stock salt added at the time of mowing. The temperatures in the two mows rose continuously, reaching a high point of 55°C. for Mow I and 54°C for Mow II on the fifth day after the hay was mowed. The temperatures of both mows dropped steadily until 1°C was reached in each on the 17th day. Following this low point the temperatures remained fairly constant at 12 to 19°C. until the end of the test when the hay was found to be brown and moldy.

Table XL.

Influence of the moisture content of sweet clover hay and the addition of salt on the temperature development in the mow. 1928.

Moisture per cent:		Mow 1 55.2	Mow 2 55.2	Mow 3 20.1	Mow 4 19.3	Mow 5 19.3	Mow 6 19.3	Air Temp
Month:	Day:	No salt:	1% Salt:	No Salt:	No Salt:	½% Salt:	1% Salt:	
		C°	C°	C°	C°	C°	C°	C°
Oct.	13	31	27	7	4	8	8	
	14	36	36	7	6	7	8	13
	15	38	39	8	6	4	6	18
	16	42	45	13	11	8	10	19
	17	44	48	19	17	15	17	13
	18	33	35	24	20	21	19	12
	19	30	34	19	19	18	16	14
	20	22	23	14	14	12	14	13
	21	26	24	15	15	14	17	15
	22	25	25	17	15	15	16	8
	23	22	24	18	15	15	16	10
	24	23	25	19	18	19	19	11
	25	25	28	21	22	22	23	8
	26	24	24	22	22	22	23	4
	27	20	19	20	20	20	21	10
	28	11	12	15	13	13	13	7
	29	3	6	9	4	4	4	2
	30	1	1	3	1	1	1	4
	31	1	1	1	1	1	1	6
Nov.	1	1	1	2	1	1	3	3
	2	14	15	15	13	13	12	3
	3	13	13	13	13	13	11	3
	4	11	12	11	13	13	11	4
	5	11	10	10	12	10	11	8
	6	11	10	11	10	5	12	8
	7	14	13	14	15	14	14	10
	8	13	15	14	11	11	13	3
	9	10	9	9	9	8	9	3
	10	12	10	9	10	7	10	6

Table XL. (Cont'd)

Month:	Day:	Mow 1 55.2 No Salt C°	Mow 2 55.2 1% Salt C°	Mow 3 20.1 No Salt C°	Mow 4 19.3 No Salt C°	Mow 5 19.3 ½% Salt C°	Mow 6 19.3 1% Salt C°	Air Temp. C°
Nov.	11	13	11	10	9	7	13	10
	12	13	13	12	12	9	13	7
	13	13	14	15	15	10	13	7
	14	18	17	20	20	20	18	15
	15	19	19	17	19	19	19	12
	16	19	20	19	16	15	19	9
	17	18	21	19	12	11	18	4
	18	17	19	17	12	10	15	2
	19	15	17	15	11	9	15	1
	20	13	13	10	10	8	13	1
	21	13	13	10	9	8	10	5
	22	12	13	9	8	8	9	4
	23	12	12	9	8	8	7	3
	24	11	12	10	9	9	7	3
	25	10	12	12	11	9	7	1
	26	10	12	12	12	10	8	1
	27	9	13	13	13	10	9	3
	28	9	12	13	13	10	9	3
	29	9	12	13	13	10	9	3
Color of Hay-		Moldy	Moldy	Green	Green	Green	Green	

Mows III, IV, V, and VI behaved similarly and no effect that could be attributed to the salting in Mows V and VI was noticed. The temperatures in these four mows rose gradually to about 22°C. on the sixth day, fell to about 1°C., then rose slightly toward the end of the experiment. The hay in all four mows was good, green hay.

Mowing Studies in 1929.

The hay for this test was cut June 21 and the mows were filled on June 23. Mows No. V and VI were filled with hay having 38 per cent moisture. Mow No. V was salted at the rate of 1 per cent salt. Mow No. IV was not filled in this test. A potentiometer borrowed from the Chemical Engineering Section was used throughout this experiment. The temperatures for the experiment are recorded in Table XLI and shown in Figure 31 for each of the mows.

In Mow No. I which contained hay having 58.29 per cent of moisture the temperature rose rapidly and on the third day after mowing had reached 74°C., after which it slowly and irregularly cooled to 50°C. The temperature of this mow was 50°C. on the 24th day after mowing. This mow produced a very dark hay although it would not be

Table XLI.

The influence of the moisture content of alfalfa on the temperature developed in the mow. 1929.

Moisture			Mow I 58.29			Mow II 34.82			Outside
			Top	Middle	Bottom	Top	Middle	Bottom	Air
Month	Day	Hour	C°	C°	C°	C°	C°	C°	Temp. C°
June	23	8:00 AM	49	43	35				26
		12:00 M	46	43	42				27
		8:00 PM	47	44	43				24
	24	8:00 AM	51	49	39				24
		12:00 M	50	54	58	33	37	41	25
		8:00 PM	57	61	65	38	33	41	21
	25	8:00 AM	72	75	76	54	55	57	27
		12:00 M	47	50	65				28
		8:00 PM	63	62	67	51	54	57	24
	26	8:00 AM	73	76	65	52	54	59	24
		12:00 M	79	71	80				26
		8:00 PM	80	79	83	50	51	57	18
	27	8:00 AM	77	73	78	50	49	54	26
		12:00 M	74	69	74				29
		8:00 PM	69	67	71	42	42	54	19
	28	8:00 AM	74	69	74	51	51	57	24
		12:00 M	65	63	71				25
		8:00 PM	67	64	65	41	38	54	22
	29	8:00 AM	69	67	69	47	50	52	28
		12:00 M	60	59	69				32
		8:00 PM	59	59	59	47	49	54	27
	30	12:00 M	62	59	59	42	45	49	31
		8:00 PM	63	59	59	42	42	49	27
July	1	8:00 AM	69	64	65	56	54	54	27
		8:00 PM	62	59	58	47	47	49	25
	2	8:00 AM	66	62	60	50	50	47	25
		8:00 PM	58	56	52				21
	3	8:00 AM	63	58	54	43	42	42	27
		8:00 PM	59	52	47				22
	4	8:00 AM	65	55	50	47	47	47	25
	5	8:00 AM	62	54	47	50	50	45	24
	6	8:00 AM	60	54	47	45	49	44	24
	7	8:00 AM	55	47	41	39	39	39	25
	8	8:00 AM	55	47	39	39	41	41	25

Table XLI. (Cont'd.)

Moisture			Mow I 58.29			Mow II 34.82			Outside Air
Month	Day	Hour	Top C°	Middle C°	Bottom C°	Top C°	Middle C°	Bottom C°	Temp. C°
July	9	8:00 AM	60	50	49	39	41	39	24
	10	8:00 AM	55	56	39	36	35	35	25
	11	8:00 AM	55	49	47	34	35	34	29
	12	8:00 AM	54	49	47	35	35	35	29
	13	8:00 AM	59	56	55	44	44	41	25
	15	8:00 AM	47	44	43	33	33	33	20
	17	8:00 AM	47	50	50	41	41	39	25
	19	8:00 AM	42	44	41	33	33	32	24
	20	8:00 AM	42	42	41	33	33	33	24
	22	8:00 AM	38	38	35	33	32	32	28
	23	8:00 AM	39	37	39	33	31	31	30
	27	8:00 AM	49	47	47	38	38	38	30
	30	8:00 AM	41	41	38	36	34	33	25
Aug.	4	8:00 AM	47	47	45	38	38	38	24
Color of Hay			Dark Brown			Brown			

Table XLI. (Cont'd.)

Moisture			Mow III 36.87		Mow V 38.08		Mow VI 38.08	
Salt			None		1%		None	
			Top	Bottom	Top	Bottom	Top	Bottom
Month	Day	Hour	C°	C°	C°	C°	C°	C°
June	26	8:00 AM			50	55	49	53
	27	8:00 AM	39	41	45	46	42	45
	28	8:00 AM	42	42	51	52	49	52
	29	8:00 AM	48	52	51	52	42	47
	30	8:00 AM	54	56	50	51	50	51
July	1	8:00 AM	63	63	56	56	51	54
	2	8:00 AM	61	67	51	51	45	52
	3	8:00 AM	57	63	47	47	43	45
	4	8:00 AM	53	63	47	47	45	49
	5	8:00 AM	57	64	53	53	47	53
	6	8:00 AM	48	49	47	48	43	45
	7	8:00 AM	40	41	39	39	35	39
	8	8:00 AM	39	40	39	39	36	39
	9	8:00 AM	39	45	41	41	39	43
	10	8:00 AM	36	37	38	38	35	35
	11	8:00 AM	35	35	39	39	34	34
	12	8:00 AM	34	35	36	37	34	35
	13	8:00 AM	40	43	43	43	40	40
	15	8:00 AM	34	40	35	35	34	35
	17	8:00 AM	40	41	46	46	46	46
	19	8:00 AM	34	35	35	35	34	34
	20	8:00 AM	35	35	34	35	33	33
	22	8:00 AM	31	33	34	35	33	34
	23	8:00 AM	34	35	35	35	34	35
	27	8:00 AM	36	39	40	40	37	37
	30	8:00 AM	34	37	33	35	30	35
Aug.	4	8:00 AM	36	37	35	36	35	39
Color of Hay			Clean Brown		Brown		Brown	

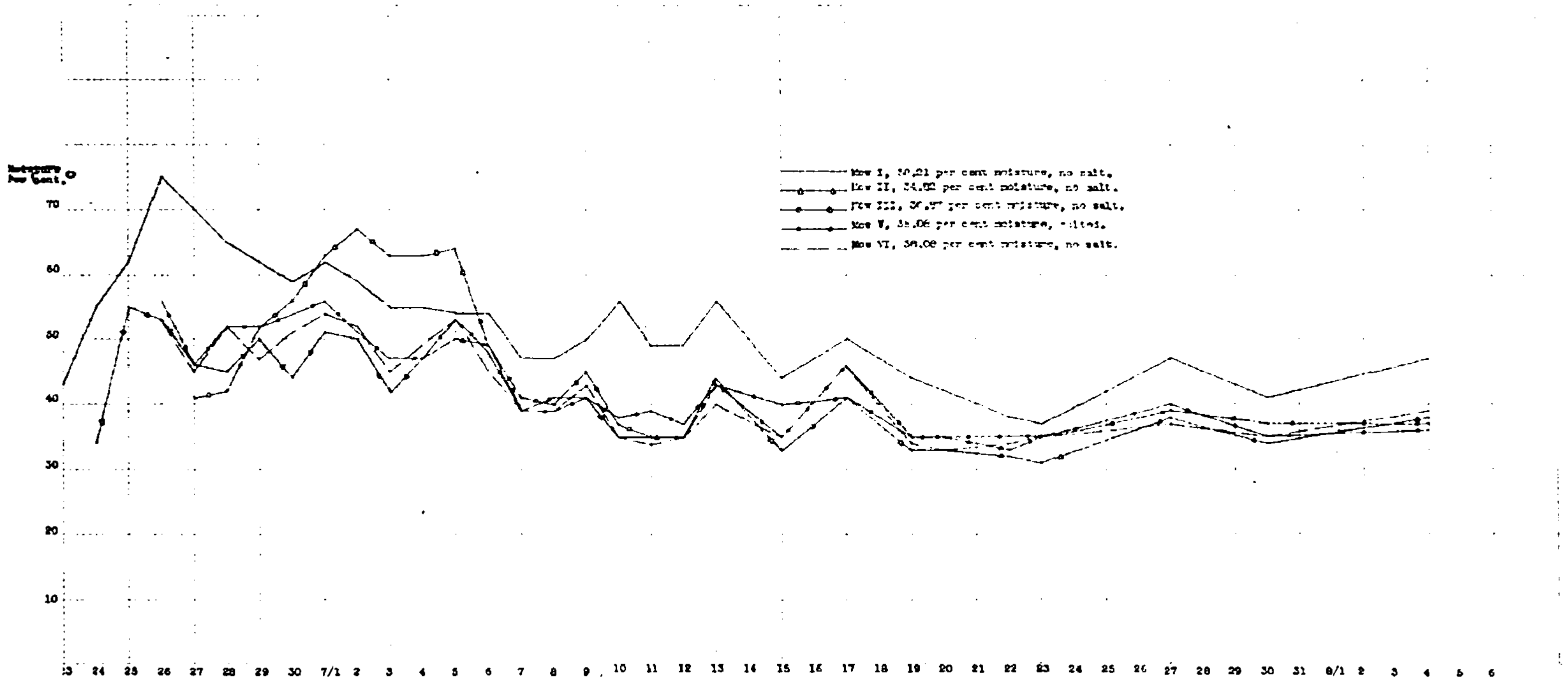

Fig. 31. A study of storage conditions in mows filled with hay of known moisture content and the influence of the moisture content of the hay and of salt on the temperature developed in the mow. 1929.

classed as black hay. There were certain small almost burned areas which indicated a very irregular heating. In the early part of the experiment the temperature in the bottom of the mow was higher than that in the top, indicating a heating area here. The highest temperature recorded in any test was the 83°C. in the bottom of Mow I on the evening of the fourth day.

Mow II filled with hay containing 34.82 per cent moisture heated to 54°C. on the first day then cooled to 44°C. after which the temperature fluctuated through a range of 8°C becoming somewhat stationary at 33°C toward the end of the experiment. The highest temperature was 54°C. The hay produced was clean, aromatic, brown hay.

Mow III, filled with hay containing 36.87 per cent moisture, heated rapidly from the time of mowing reaching its highest temperature of 67°C on the 5th day after mowing. After this steep rise the temperature remained above 60°C. for four days then fell to slightly below 40°C for the remainder of the experiment. The hay in the mow was clean brown hay of the best quality produced in any of the tests.

Mow No. V and VI were heating above 50°C at the start of the measurements, the temperatures fell slightly in each mow and then rose to the highest temperature recorded for the mows on the fifth day. The temperature in Mow V reached 56°C. while that in VI was 54°C. From this point the trend in temperature was downward.

The carbon dioxide and oxygen in the air of the mow were determined at intervals throughout the experiment. The per cent carbon dioxide and oxygen in the air of each mow is given in Table XLII. It will be noted that the carbon dioxide content of the hay is quite high in Mow I, which has a moisture content of 58.29 per cent. The rapid rise in carbon dioxide from the first agrees well with the temperature developing in the mow. It is thought that channels were formed which tended to permit the escape of the gas toward the last of the experiment. The 9 per cent carbon dioxide found in this mow is the highest concentration of this gas found in the mowing tests. A higher carbon dioxide content would have been expected in Mow III in view of the heating in this mow but in all of these tests it is rather difficult, with well-cured hay, to pack it in the mow tight enough to prevent the diffusion of the gas. Hay that is green as was the case in Mow I packs tightly together and prevents the diffusion of the gas. No appreciable difference can be noted between the carbon dioxide

Table XLII.

The influence of the moisture content of alfalfa hay on the percent of carbon dioxide and of oxygen present in the mow. 1929.

		Mow I		Mow II		Mow III		Mow V		Mow VI	
Moisture Per Cent		58.29		34.82		36.87		38.08		38.08	
Month	Day	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2
								Salted			
June	23	4.9	16.3								
	24	3.5	16.5	0.8	21.0						
	25	5.8	15.6	0.8	18.8						
	26	8.0	13.2	0.8	18.8			0.6	20.0		
	27	8.2	12.0	2.0	19.8			1.0	19.2	0.6	19.0
	28	9.0	11.6	2.6	18.0	1.4	19.6	2.2	18.4	1.2	19.9
	29										
	30	3.5	19.0	1.0	19.8	3.0	18.0	3.5	18.5	3.2	18.8
July	1	3.5	19.0	2.5	18.7			1.8	19.7	1.9	18.4
	2	1.8	19.6	0.4	20.0	2.6	18.6	0.4	20.4	1.8	19.4
	3										
	4										
	5			1.2	18.0			1.2	19.2	2.0	18.8
	6										
	7										
	8										
	9	2.0	19.1	1.8	19.4	0.8	19.4	1.7	19.0	1.0	19.4

evolved in the salted Mow V in comparison with the unsalted Mow VI.

The mows were filled a second time in 1929 on August 15th with hay cut on August 14. Mows I, II and III were filled with uniform green hay with 31 per cent of moisture. Mow I was not salted; mow II had ½ per cent of salt; and mow III, 1 per cent of salt.

The temperatures for the duration of the experiment as given in Table XLIII indicate a general lack of heating in any of the mows. The tendency of so many mows to produce brown rather than green hay led to the filling of these mows with hay which might be expected to cure out and retain its green color. Mows I, II and III did not heat excessively and no difference could be noted in the tendency of the hay in the salted mows to heat less than that in the unsalted ones.

Mows IV, V and VI did not heat excessively. Mow IV heated immediately to 39°C then cooled at once. The highest temperature was reached in Mows I and II on the 3rd day, in Mow III on the second day, in Mow IV on the first day and in Mow V and VI on the 9th day. The hay in Mows I, II and III were light brown at the end of the test with a slight mold development. The hay in Mows IV, V and VI was green in color and graded U.S.No. 2 hay.

Table XLIII.

The influence of varying moisture content of alfalfa hay and of the use of salt on the temperature developed in mows. 1929.

		Mow I	Mow II	Mow III	Mow IV	Mow V	Mow VI
Moisture Per cent		31.2	31.2	31.2	28.6	24.89	20.0
Salt Per cent		0	0.5	1.0	0.0	0.0	0.0
Month	Day	C	C	C	C	C	C
August	16	25	15	16	23	21	
	17	19	29	16	23	21	
	18	23	23	12	25	20	25
	19	20	23	17	30	19	20
	20	26	26	18	39	29	23
	21	26	30	24	31	26	20
	22	23	24	20	26	22	18
	23	33	33	23	22	29	15
	24	18	24	20	22	19	14
	25	16	18	16	22	18	7
	26	18	19	14	21	21	12
	27	18	26	22	30	28	17
	28	30	35	22	26	33	25
	29	26	24	20	25	26	16
	30	24	25	22	23	25	18
	31	16	20	15	19	18	14
Sept.	1	16	17	16	18	19	10
	2	18	20	18	21	20	15
	3	19	20	20	18	20	15
	6	14	14	14	16	14	10
	10	21	22	26	24	25	21

Mowing Studies in 1930.

As in the studies of 1928 and 1929 each mow was filled with 400 to 500 pounds of hay. The hay for this study was leafy alfalfa cut in the 1/10 bloom stage. Three thermocouples were placed in the center of each mow, one near the top, one near the center and the other near the bottom. The temperatures were read every two hours until they became steady, then two or three times daily thereafter. A portion of the data collected on the temperatures in the mow is given in Table XLIV. The temperatures at the middle of the mows are shown graphically for the duration of the experiment in Fig. 32.

It will be observed that as a general rule the temperature rose during the day and was higher at 8 P.M. than at the 8 A.M. reading. Temperature determinations were made at top, middle and bottom points in each mow. As a general rule the top of the mow was the warmer and the bottom the cooler of the three locations. Generally the spread between the top and the bottom was very small, howêver in mow IV a spread of 12°C was observed between the top and the bottom of the mow over a period of three days the top of the mow being the warmest throughout this period.

Table XLIV.

The influence of the moisture content of alfalfa hay on the temperature developed in top, middle and bottom of the mow. 1930.

Moisture Content			Mow Number One 39.04			Mow Number Two 33.73			Mow Number Three 33.73		
Month	Day	Hour	Top C°	Middle C°	Bottom C°	Top C°	Middle C°	Bottom C°	Top C°	Middle C°	Bottom C°
						1% Salt					
June	20	12M	40	39	37	50	50	47	50	51	48
		8PM	39	38	35	48	47	43	48	48	46
	21	8AM	38	38	38	46	45	44	48	47	45
		12M	35	35	33	45	43	42	44	43	43
		8PM	35	35	34	43	42	40	43	41	40
	22	8AM	39	44	48	39	41	43	40	41	40
		12M	39	44	48	39	41	43	40	41	40
		8PM	50	54	59	45	49	52	43	49	49
	23	8AM	53	51	51	52	54	54	53	53	52
		12M	53	53	54	50	53	53	52	52	52
		8PM	54	53	55	52	53	53	53	53	54
	24	8AM	52	52	52	53	52	52	52	53	52
		12M	52	51	50	52	51	52	50	54	50
		8PM	52	51	53	48	53	52	52	52	52
	25	8AM	49	52	54	50	51	52	55	56	55
		12M	52	51	52	49	50	50	54	54	53
		8PM	52	50	50	50	50	53	50	52	53
	26	8AM	52	50	52	54	53	53	55	57	55
		12M	52	51	50	53	52	51	54	55	54
		8PM	50	45	50	49	50	50	54	54	53

Table XLIV. (Cont'd.)

Moisture Content			Mow Number One 39.04			Mow Number Two 33.73			Mow Number Three 33.73		
			Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
Month	Day	Hour	C°	C°	C°	C°	C°	C°	C°	C°	C°
June	27	8AM	53	51	51	50	50	51	54	55	54
		12M	54	53	54	51	52	52	53	54	53
		8PM	54	52	55	53	55	55	55	57	57
	28	8AM	55	54	55	54	53	52	55	55	54
		12M	54	54	54	51	50	50	53	53	52
		8PM	54	53	53	50	49	49	52	52	52
	29	8AM	50	49	50	45	45	45	50	48	48
		12M	48	48	49	44	45	45	50	49	48
		8PM	48	48	48	44	47	47	51	50	50
	30	8AM	48	46	47	47	47	46	51	51	50
		12M	50	48	50	49	50	48	52	52	50
		8PM	48	46	48	50	50	48	51	50	50
July	1	8AM	48	43	45	48	50	47	49	50	48
		12M	47	43	43	49	50	46	47	47	47
		8PM	47	44	45	51	53	49	49	50	49
	2	8AM	49	45	44	45	47	44	40	43	43
		12M	48	44	45	46	48	44	43	45	43
		8PM	50	48	50	47	50	49	48	48	45
	3	8AM	50	47	49	45	45	45	41	43	41
		12M	52	49	49	45	44	44	42	42	40
		8PM	50	49	50	45	49	48	46	43	41
	4	8AM	50	49	49	48	49	48	46	43	41
		12M	51	49	49	50	50	49	46	43	41
		8PM	49	48	50	50	48	47	45	44	45
	5	8AM	49	47	48	48	49	47	50	46	42
		12M	50	48	50	50	48	47	52	47	43
		8PM	52	51	51	52	48	47	53	49	43
	6	8AM	53	53	54	51	49	49	52	50	45
		12M	53	53	54	53	50	49	51	52	48
		8PM	52	52	53	54	53	49	55	54	50

Table XLIV. (Cont'd.)

Moisture Content			Mow Number One 39.04			Mow Number Two 33.73			Mow Number Three 33.73		
Month	Day	Hour	Top C°	Middle C°	Bottom C°	Top C°	Middle C°	Bottom C°	Top C°	Middle C°	Bottom C°
July	7	8AM	52	50	50	50	49	48	52	52	48
		12M	51	50	51	50	48	45	52	50	48
		8PM	50	50	48	52	50	47	52	51	48
	8	8AM	50	50	48	49	47	45	51	49	45
		12M	49	49	47	47	45	43	50	48	44
		8PM	47	48	48	49	47	44	50	48	44
	9	8AM	48	47	45	43	41	41	46	45	41
		12M	48	48	48	46	43	43	48	48	43
		8PM	49	53	50	49	47	44	51	50	46
	10	8AM	49	50	47	42	40	39	46	44	41
		12M	49	51	48	45	43	42	49	46	43
		8PM	50	50	52	48	44	43	52	49	47
	11	8AM	49	50	46	42	40	39	47	43	41
		12M	49	51	48	45	41	48	48	44	40
		8PM	47	48	45	45	40	39	51	43	39
	12	12M	48	50	46	44	39	38	47	42	40
	14	12M	43	40	37	37	31	30	38	35	32
	15	12M	35	30	25	30	24	23	28	26	24
	16	12M	35	25	21	24	20	19	23	22	21
	17	12M	29	25	21	23	19	18	23	20	20
	18	12M	37	38	27	25	21	21	35	23	23
	20	8AM	43	43	36	37	30	29		32	29
	22	8AM	37	36	36	37	32	29		33	32
	29	8AM	34	36		34	32	32	34	34	34

Table XLIV. (Cont'd.)

Month	Day	Hour	Mow Number Four: Top C°	Mow Number Four: Middle C°	Mow Number Four: Bottom C°	Mow Number Five: Top C°	Mow Number Five: Middle C°	Mow Number Five: Bottom C°	Mow Number Six: Top C°	Mow Number Six: Middle C°	Mow Number Six: Bottom C°
Moisture Content			32.20			29.76			18.65		
June	20	8AM									
		12M	48	48	48	50	49	46	43	42	32
		8PM	43	42	42	43	44	43	40	40	32
	21	8AM	45	44	41	42	43	41	37	38	31
		12M	44	42	40	41	40	39	36	35	29
		8PM	38	38	37	37	37	35	36	35	32
	22	8AM	39	39	39	35	34	35	35	35	31
		12M	39	39	39	35	34	35	35	35	31
		8PM	39	42	43	36	38	36	36	37	
	23	8AM	44	49	50	32	35	35	33	35	33
		12M	44	47	47	32	35	36	35	38	34
		8PM	48	50	50	31	34	38	33	38	39
	24	8AM	53	50	49	37	43	45		41	39
		12M	52	50	50	38	43	44	38	39	39
		8PM	53	53	55	40	43	43	40	42	43
	25	8AM	52	53	50	42	47	47	40	42	41
		12M	49	49	46	41	45	44	40	42	40
		8PM	47	48	47	42	47	45	40	44	43
	26	8AM	52	53	51	45	48	47	38	42	39
		12M	49	47	46	44	45	43	40	41	40
		8PM	47	47	48	45	48	46	43	45	43
	27	8AM	54	53	51	47	49	48	40	39	36
		12M	50	47	49	47	49	47	40	38	36
		8PM	49	51	51	47	49	49	43	41	40

Table XLIV. (Cont'd.)

Moisture Content			Mow Number Four 32.20			Mow Number Five 29.76			Mow Number Six 18.65		
Month	Day	Hour	Top C°	Middle C°	Bottom C°	Top C°	Middle C°	Bottom C°	Top C°	Middle C°	Bottom C°
June	28	8AM	50	49	47	46	48	46	38	37	32
		12M	50	49	49	48	51	48	40	38	35
		8PM	50	49	48	48	50	48	39	37	29
	29	8AM	47	45	43	45	48	45	39	38	33
		12M	48	48	46	48	49	47	41	42	38
		8PM	52	51	50	49	52	49	43	43	41
	30	8AM	50	48	44	48	49	47	40	40	34
		12M	50	49	45	48	50	47	41	40	36
		8PM	48	49	44	45	47	44	41	41	38
July	1	12M	48	45	39	44	44	40	38	38	32
	2	12M	49	45	37	40	38	34	36	34	28
	3	12M	45	40	32	34	34	32	32	32	25
	4	12M	45	45	33	32	33	31	33	33	32
	5	12M	42	37	32	33	34	32	35	35	29
	6	12M	43	43	40	39	42	40	39	38	31
	7	12M	45	43	39	40	42	40	35	35	32
	8	12M	43	42	39	38	41	39	33	33	30
	9	12M	41	43	40	39	40	38	33	34	32
	10	12M	40	40	38	38	40	38	34	33	32
	11	12M	40	40	38	37	40	38	32	33	32
	12	12M	38	38	35	35	38	36	31	31	30
	13	12M	33	34	32	32	34	32	26	28	27

Table XLIV. (Cont'd.)

Moisture Content			Mow Number Four 32.20			Mow Number Five 29.76			Mow Number Six 18.65		
			Top	Middle	Bottom	Top	Middle	Botton	Top	Middle	Bottom
Month	Day	Hour	C°	C°	C°	C°	C°	C°	C°	C°	C°
July	14	12M	29	29	25	26	29	26	23	24	22
	15	12M	20	20	19	19	23	21	18	19	19
	16	12M	19	19	19	18	19	19	18	16	19
	17	12M	19	19	21	20	19	20	22	19	19
	18	12M	21	22	25	22	21	22	23	22	22
	22	8AM	25	25	28	27	28	26	24	24	22

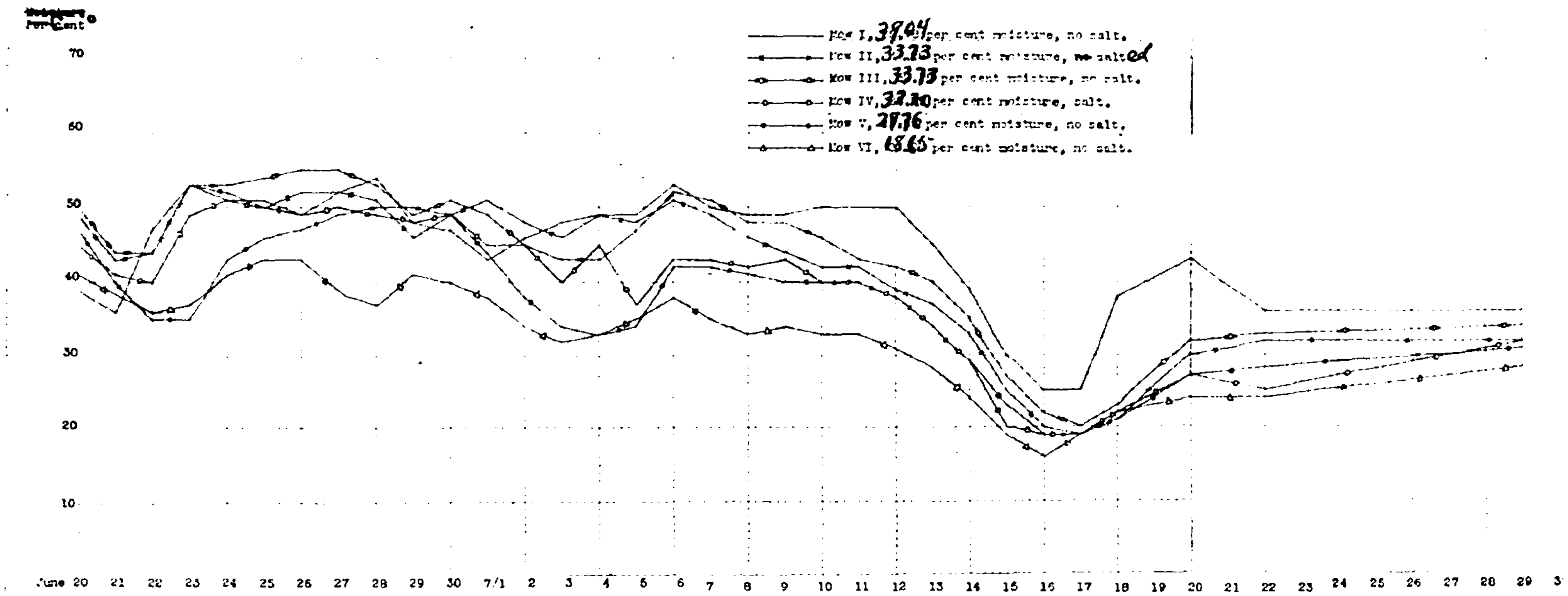

Fig. 32. A study of storage conditions in mows filled with hay of known moisture content and the influence of the moisture content of the hay and of salt on the temperature developed in the mow. 1930.

All of the mows were heating at the time of the first temperature determination and cooled in one day's time then heated again reaching the highest temperature of the experiment within 8 days. Mow I, II, and III remained close to 50°C. for 18 days. At the end of this time all mows cooled strikingly below 25°C due to a cool, moist period. The temperatures of all mows, with the exception of Mow I rose to around 30°C after the cooling and remained at this level until the end of the experiment. The temperature in Mow I rose to 43°C after the sudden cooling.

The three mows, Mow I with 39.04 per cent moisture and Mow II and III with 33.73 per cent each behaved almost identical in degree of heating for the first 20 days. Mow IV with 32.20 per cent moisture heated on the fifth day to above 50°C and remained heating moderately until the low point was reached on July 16 after which this mow did not again become hot. Mow V with 29.76 per cent moisture resembled Mow IV very closely in the course of its heating and produced good green hay in the end. Mow VI with 18.65 per cent moisture heated to 42°C at the time it was being packed in the mow cooled with the others then heated again to 43°C. after which it cooled and did not again heat during the experiment.

The hay in Mows IV and V was good, green hay. The salted hay in Mow II produced hay that was slightly green and decidedly not so moldy as the brown hay in Mow III. The hay in Mow I was gray and very moldy.

The carbon dioxide and the oxygen present in the mows as determined at varying intervals throughout the period of the curing in 1930 are indicated in Table XLV. As in previous tests the carbon dioxide content is greatest in the mow with the highest percentage of moisture. The carbon dioxide content rose to 6 per cent on the third day after which it maintained a rather high concentration until the end of the experiment. The carbon dioxide content of Mow II was somewhat lower than Mow III which had the same moisture content (33.73 per cent) but no salt. This was true throughout the test. The carbon dioxide in these mows runs higher because there was less leakage due to the fact that the mows were newly lined with black building paper before being filled.

The carbon dioxide content of Mow IV and V is practically the same, likewise the moisture content of the hay and the temperatures developed were practically equal. These mows did not appear so compact at the end of the test as Mows II and III.

Table XLV.

The influence of the moisture content of alfalfa hay on the amount of carbon dioxide and of oxygen present in the mow. 1930.

		Mow Number One		Mow Number Two		Mow Number Three	
Moisture		39.04		33.73		33.73	
Month	Day	CO_2 Per Cent	O_2 Per Cent	CO_2 Per Cent	O_2 Per Cent	CO_2 Per Cent	O_2 Per Cent
June	21	3.0	19.0	2.5*	18.5*	2.7	19.0
	23	5.0	18.0	3.5	18.5	3.5	18.0
	24	6.	16.	2.9	19.1	5.0	16.5
	25	4.75	17.0	4.3	17.7	4.3	17.7
	26	4.9	16.6	3.6	17.9	5.5	16.0
	27	4.5	17.0	5.0	16.7	5.9	16.1
	28	4.0	18.0	3.0	19.0	5.8	16.0
	29	3.1	19.3	1.5	20.5	5.0	17.0
	30	3.0	19.4	2.1	20.4	3.1	19.3
July	1	3.1	19.3	3.0	19.4	2.1	20.3
	2	3.1	18.3	2.2	19.9	2.1	20.0
	3	3.0	18.5	2.0	19.5	2.5	19.0
	5	3.5	18.0	2.2	19.9	3.0	19.0
	6	3.9	18.1	3.0	19.0	4.0	17.5
	8	3.0	18.5	2.1	19.4	2.5	19.0
	11	2.1	20.0	1.1	21.4	1.2	20.0
	14	1.0	21.0	1.0	21.0	0.8	21.0

* Mow number two salted.

Table XLV (cont'd)

The influence of the moisture content of alfalfa hay on the amount of carbon dioxide and of oxygen present in the mow. 1930.

		Mow Number Four		Mow Number Five		Mow Number Six	
Moisture		32.20		29.76		18.65	
Month	Day	CO_2 Per Cent	O_2 Per Cent	CO_2 Per Cent	O_2 Per Cent	CO_2 Per Cent	O_2 Per Cent
June	21	2.5	18.5			2.2	20.0
	23	3.0	18.5	2.5	19.0	1.5	20.0
	24	3.5	18.0	4.0	17.0	1.75	19.75
	25	2.0	19.0	2.0	19.0	1.5	19.5
	26	4.1	16.9	4.5	16.7	0.2	21.0
	27	3.7	17.8	4.0	18.0	2.9	19.1
	28	3.8	18.1	4.0	18.0	2.6	19.4
	29	3.9	18.0	4.0	18.0	2.2	19.1
	30	2.5	19.9	2.3	20.1	1.0	21.0
July	1	2.1	20.3	2.0	20.4	1.0	21.4
	2	2.1	20.4	2.0	20.5	1.0	20.0
	3	2.1	19.4	1.5	20.0	1.0	20.0
	5	2.7	19.3	2.0	20.0	1.4	21.4
	6	2.5	19.5	2.2	19.5	1.1	21.1
	8	1.5	20.0	1.7	19.8	0.5	21.3
	11	0.75	21.2	1.2	20.1	0.5	21.3
	14	0.5	21.4	0.7	21.1	1.0	20.8

Mow VI did not heat and only a limited carbon dioxide production was evident. In practically all cases the high carbon dioxide content comes during the time of the highest temperatures. The gas analysis was not made during the extremely low drop in the temperatures of all mows occurring on July 16.

Studies on the Effect of Baling Alfalfa Hay from the Field

The influence of the moisture content of alfalfa hay on the heating and quality of the hay when baled has been tested in four experiments. Alfalfa hay was baled in the field with a baler mounted on a tractor and with a hay loader attached. This baler moved across the field, picking the hay up out of the windrow and baling it as it went.

Experiment Number I.

The hay was cut on August 22 and 23, 1927. Hay was baled with the moisture content ranging from 20 to 36 per cent. Three bales were tagged for each lot of hay baled and stored in a cool somewhat humid room. Temperature readings in each bale were made by the use of a potentiometer and thermocouples.

The highest temperature recorded was 60°C. The detailed record of temperatures in this series was lost.

The bales were graded at the end of the test and hay with 23, 22.5 and 20 per cent moisture graded No. 2 green hay, although the outside of the bales was heavily molded. Hay with 26, 29, 32 and 36 per cent of moisture had lost all green color and was classed as sample grade. One bale with 27 per cent of moisture had some green color and was graded No. 3. There was not the definite line of demarkation that this classification might indicate. Hay with 26 per cent of moisture made an excellent, clean, brown hay free from "dustiness."

Experiment Number II.

In 1928, hay grown on rich bottom land was baled on August 17, at moisture contents varying from 16.07 to 30.3 per cent. Twelve bales were arranged in a barn for temperature studies. Thermocouples were placed in each bale. Some of the bales were salted at the time of baling by sprinkling salt into the hay as it went into the press. The temperatures and the grade of the hay produced is given in Table XLVI. The grading was done by Prof. C. S. Dorchester.

The heating in the bales of hay was not excessive. The extreme variations in the temperatures cannot be accounted for other than to suggest that the changes in

Table XLVI.

The influence of the moisture content of alfalfa hay and of adding one per cent salt on the temperature developed in bales of hay. 1928.

		Bale 1	Bale 2	Bale 3	Bale 4	Bale 5	Bale 6
Moisture Per Cent		19.2	19.2	23.55	16.07	23.55	30.3
Month	Day	Salted C°	C°	Salted C°	C°	C°	Salted C°
August	17	12	7	14	16	19	19
	18	11	13	11	6	5	15
	19	20	21	25	23	12	16
	20	15	13	14	13	17	16
	21	9	15	6	7	5	16
	22	13	7	28	10	5	7
	23	16	4	9	18	15	12
	24	7	5	7	14	12	7
	25	6	4	22	10	7	10
	26	14	3	16	19	11	18
	27	6	1	26	24	23	16
	28	12	14	20	14	20	22
	29	20	20	18	18	16	17
	30	13	14	16	14	14	16
	31	14	16	14	12	9	11
Sept.	1	12	14	16	12	12	12
	2	14	18	16	14	15	15
	3	11	12	14	11	15	14
	6	16	14	15	12	15	12
	10	25	23	20	19	21	20
Bale Weight		70	70	57	50	57	56
U. S. Grade		No. 2	No. 3	No. 3 Leafy	No. 2	No. 2	No. 1

Table XLVI. (Cont'd.)

Moisture Per Cent		Bale 7 30.3	Bale 8 16.07	Bale 9 16.07 Salted	Bale 10 30.3 Salted	Bale 11 30.3	Bale 12 23.55
Month	Day	C°	C°	C°	C°	C°	C°
August	17	17	16	19	16	21	
	18	12	11	7	14	25	12
	19	21	17	22	15	32	20
	20	32	20	19	19	34	16
	21	31	18	17	15	30	12
	22	30	11	9	11	25	10
	23	34	14	14	18	31	25
	24	25	7	3	6	30	28
	25	16	10	4	7	28	15
	26	17	21	8	14	25	20
	27	26	15	22	16		25
	28	29	19	12	13		22
	29	23	18	15	19		17
	30	23	16	9	12		20
	31	16	19	3	8		15
Sept.	1	12	12	9			16
	2	15	16	9	7		15
	3	13	12	7	9		13
	6	15	15	5	4		13
	10	25	21	16	18		23
Bale Weight		74	55	53	58	92	48
U. S. Grade		Sample	No. 2	No. 2	No. 1	No. 2	No. 3 Leafy

the conditions for evaporation of the moisture from the hay may be responsible. The behavior of these bales also was somewhat erratic from the standpoint of the quality of the hay produced. Hay baled with 16.07 per cent of moisture produced bales grading U. S. No. 2, and with 19.2 per cent of moisture U. S. No. 2 in the salted hay and U. S. No. 3 in that not salted. Hay with 23.55 per cent of moisture produced U. S. No. 2 in the not salted and U. S. No. 3, leafy in the salted hay. Hay with 30.3 per cent of moisture when salted produced two bales grading U. S. No. 1 and that not salted produced a U. S. No. 2 and a sample grade bale.

Hay with 23.85 per cent of moisture or less appeared perfectly safe to bale.

Experiment No. III.

Hay at the Agricultural Engineering farm was baled with varying moisture contents. When the hay was about one-half cured, the baler was used to make two bales. This was repeated at intervals of two hours until the entire field was fully cured. These bales were tagged and the temperature determined daily until it became constant. The temperatures recorded and the grade of hay produced in these bales are as shown in Table XLVII.

Table XLVII

Influence of moisture content of alfalfa hay on the temperature developed in bales of the hay. 1928

Moisture per cent:			One	Two	Three	Four	Five	Six
			37.4	37.4	32.4	32.4	26.3	26.3
			Temp	Temp	Temp	Temp	Temp	Temp
Month	Day	Hour	C°	C°	C°	C°	C°	C°
Aug.	21	3 PM	50	48				
	25	12 N	56	60	50	50	29	28
	26		58	60	58	55	39	42
	27		55	57	57	55	44	44
	28		53	54	55	52	46	45
	29		53	55	57	56	49	48
	30		52	49	55	52	53	45
	31		53	54	53	54	50	48
Sept.	1		52	53	48	51	49	49
	2		50	52	45	50	48	52
	3		50	51	49	55	49	52
	4		45	45	38	48	39	45
	5		33	34	28	43	30	38
	6		25	23	23	30	22	27
	7		23	22	20	27	20	21
	9		27	22	22	23	21	21
	10		21	18	19	20	18	18
	11		19	16	17	20	17	18
	12		21	19	18	26	18	19
	14		15	15	16	16	16	16
U. S. Grade			Sample	Sample	Sample	Sample	No.3	No.3

It will be seen that hay with 32 per cent of moisture, or more, did not produce good hay. The highest temperature produced was found in bale No. 2 on the second day of the test. The temperature in each of the first four bales exceeded 55°C. and the green color was destroyed in the centers of the bales. In bales 5 and 6 considerable heating occurred and the bales did not have full green color.

Experiment Number IV.

Hay was baled on June 29, 1929, on the Agricultural Engineering farm. The hay was three-fourths field cured when the first three bales were made. At intervals of two hours, additional sets of three bales were made until the hay was cured. The last set of bales was made after the general field had been baled. The temperatures developed in the bales and the grade of hay produced are given in Table XLVIII.

Two bales of each moisture content were used for the temperature determinations. In each of the two D bales, the temperature went above 50°C. and they were brown inside.

The data would indicate that hay with over 30 per cent of moisture cannot be baled with safety. Hay with

Table XLVIII

The influence of moisture content of alfalfa hay on the temperature developed in bales of the hay. 1929.

		Bales A	Bales B	Bales C	Bales D	Bales E
Moisture when baled		32.02	37.67	22.71	17.64	15.00
Date baled		June 29	June 29	June 29	June 29	June 30
Month	Day	C°	C°	C°	C°	C°
June	29	42	41			
	30	42	50	40	37	
July	1	46	38	34	33	
	2	48	41	31	35	
	3	51	43	30	39	
	6	50	51	39	51	35
	9	46	50	42	40	42
	10	41	42	40	34	34
	11	48	48	46	41	42
	15	34	31	33	30	30
	16	30	31	33	29	28
	17	30	28	28	30	29
	18	29	25	27	27	26
	20	23	21	22	23	21
	21	30	29	28	29	29
	26	33	34	36	32	32
Aug.	4	23	23	24	23	22
U. S. Grade		Sample	Sample	No. 2	Sample	No. 2

below 22 per cent would ordinarily be considered safe although the D bales in this test with 17.64 per cent of moisture lost their green color and were graded as sample. Sample grade hay was produced in the A, B, and D bales, with a temperature of above 50°C. The degree of compression and the freedom with which the carbon dioxide may escape from the bale are probably important factors accounting for these results.

Discussion.

The need of more information on the cause of heating and of spontaneous combustion becomes evident in a review of the literature on the subject. The initial heating, up to 40-45°C., has been credited (1) to the respiration of living cells in the plant, (2) to the growth of microorganisms, (3) to a purely chemical oxidation, and (4) to the action of plant enzymes released from the cells.

In none of the rather extensive experiments, of Hildebrandt (27) and of Miehe (53), has sterilized hay heated. This would tend to discredit all of the theories advanced to account for the preliminary heating stage except that relating to the microorganisms. On the other hand, the sterilization may have killed the plant cells, destroyed the enzymes, and disturbed the chemical relationships, thus inhibiting their normal work. Both bacteria and molds have been found capable of bringing on the preliminary heating stage when sterilized hay was inoculated with the microorganisms. If the actions of microorganisms is given credit for this preliminary stage of heating, the means by which it has been brought about is still questionable. Is the heating due to the heat of respiration of these thermophiles or are they, as Browne (8) suggests, merely the means of preparing unstable, unsaturated compounds for the chemical oxidation process which causes the heating?

The heating between 40-50°C. is credited to the same causes as that between air temperature and 40-45°C. with the exception of the living plant cell. Thermophilic fungi are supposedly the ones which work most in the range between 40 and 50°C. While Miehe, in particular, credits thermophilic bacteria, particularly, B. Calfactor with the heating from 50 to 65°C.,Hildebrandt (27) believes that the Fungi may be much more responsible for the higher temperatures than has been thought in the past.

The presence of life in the cells of cured hay plants was demonstrated, further work will be necessary before the presence of this life in the cells can be shown to be or not to be the cause of the heating of the hay. Practically all writers agree that both the living plant cell and the microorganisms are not directly responsible for the heating from 70°C. to the ignition point.

Laupper's (40) views of the formation of pyrophoric iron, and Ranke's pyrophoric carbon theory, which involve high temperatures or long periods of heating, certainly do not hold true in all cases.

Truninger used an apparatus to determine the ignition point of hay and found the ignition point to vary from 190°C. to 226°C. This apparatus was tested in the laboratory and a sample of normally cured hay was found to ignite at 190°C. The apparatus consisted essentially of two flasks in an oven, one flask held the hay sample to be ignited the other was filled with glass beads. The two flasks were so connected that a stream of air could be heated as it passed through the glass beads and then the warm air delivered into the bottom of the flask containing the hay. Thermometers in each flask indicated their respective temperatures. Heat was applied to the oven enclosing the flasks until both thermometers registered 160°C. at which time the heat was checked and maintained at this point. The rise in temperature in both thermometers stopped for a short time then while the thermometer in the glass beads registered 160°C. the one in the hay rose quickly to 190°C. at which point the hay ignited with explosive violence.

After witnessing the rapid rise in temperature in the hay flask one would be led to credit chemical oxidation with the greater portion of the responsibility for spontaneous heating and ignition of hay.

In practically all of the mowing experiments there was a rather striking agreement with the two periods of heating reported by Miehe and Cohn. The hay which heated rapidly soon after being mowed, after a brief rise in temperature cooled somewhat, then slowly heated again. The highest temperature in the mows of practically cured hay was generally reached between the sixth and tenth day after the hay was put in the mow. After a period of six weeks the hay in the small mows had generally cooled to air temperature.

The localized heating center is indicated by the fact that in any of the mows in the early part of the heating period, the temperatures in the bottom of the mow were often higher than in the top, although later on the reverse was generally true. In the experiment where cold air was blown through the heating hay definite centers of heating could be observed by changing the location of the thermometer two or three inches. This observation of small intensively hot areas, surrounded closely by cooler layers of hay, is in line with the observations of Ranke (64), Laupper (40), and James (32).

One other observation that would tend to place the emphasis of the heating on chemical oxidations is the sudden heating of stacks of hay which occurred a few years ago in a flooded region in Vermont. There was no noticeable heating of this hay prior to the flood. The water rose on the stacks to a depth of 17 feet on Friday morning. Heating was noticed on Sunday morning and the hay burned on Monday. Unless the microorganisms had prepared the hay previously they could scarcely be credited with this fire.

It would seem that microorganisms are important in the early stages of the heating of hay, the fungi in the early ranges of heating and the bacteria in the entire range, from air temperatures up to 70°C. Chemical oxidations probably enter at a very early period, if not at the start of the heating, and such oxidations probably play an increasing part as the temperature is raised. The part which respiration of the living cells of the plant may have in producing the temperatures observed in the early stages of the heating period can not be ignored. Observations have shown that when hay is cured out rapidly and then packed into a mow, there often is an accumulatioh of heat within a few hours, while hay cured out slowly, perhaps with a larger per cent of the cells dead, heats more slowly at first. It would seem that there should be as many, if not more, microorganisms present in the slowly cured hay and that it should therefore heat more rapidly if the microorganisms alone were responsible for the early heating.

Fungi are thought to be more important in the lower ranges of heating, due to the fact that hay which heats slowly is usually moldy, while hay which has more moisture heats quickly to a higher range and cures out to a mold-free brown hay. When hay heats slowly, with the developement of molds, and then later rises to the higher range of 55°C. and above, the molds that were present are killed and the hay is "dusty".

The green color in hay seems to be destroyed with a temperature of 50 to 55°C. and above. The temperature is not thought to cause the brown color in hay but it is believed to be instrumental in checking molds. The temperature is a result of the respiratory activities of the microorganisms and of the chemical oxidations in the lower ranges. The elevation of the temperature stimulates the chemical oxidation. Without an accumulation of other products, particularly carbon dioxide, the high temperatures could be encountered by the hay without a loss of its green color.

In no case did hay which had heated above 55°C. have a full green color and in many cases the color was destroyed when the temperature did not reach 50°C. But in many cases green hay was produced in the bale and in containers with temperatures approximately 50°C. The real brown hay is formed at temperatures above 50 to 55°C. Rapid heating of the hay seems essential in the production of brown hay. Hay which had heated to 40°C. in the experimental mows was brown or gray in color but it was not the desired soft, aromatic, brown hay. Black hay has never been produced in our mowing studies, although in 1929 hay was produced which had very dark brown areas in it.

Hay with 32 per cent of moisture when placed in the mow retained its full green color and made excellent hay in the 1930 mowing test. This represents the maximum moisture content at which the hay retained its green color in any of the tests. In no case did dangerously high temperatures result when the hay had less than 35 per cent of moisture. Hay with 36.87 per cent of moisture heated to 67°C. The most radical heating occurred in hay having 58.27 per cent of moisture at the time it was placed in the mow. The highest temperature reached in this hay was 83°C., which is the highest temperature observed in any of the hay curing studies. Accompanying this extreme heating, the carbon dioxide, produced was the highest in any of the mowing tests, reaching 9 per cent of the air in the mow.

In general, hay may be expected to be safe from dangerous overheating when it contains less than 30 per cent of moisture. Hay with 25.89 per cent of moisture lost its green color in the mow in one trial, although from other tests one would not expect this.

The loss of color occurs under conditions which favor the collection of the carbon dioxide. In every case where even slight heating occurred in the small containers but with the formation of carbon dioxide the hay lost its green color. This is probably due to the production of weak carbonic acid by the solution of carbon dioxide in water which, according to Onslow (52), transforms the chlorophyll to phaeophytin.

The same brown color results in hay which softens, becomes sticky and is pressed into a compact layer in the mow thus leading to the accumulation of carbon dioxide.

Carbon dioxide evolved in heating hay is generally highest in those mows with the higher moisture contents and in which the higher temperatures occur. A record of the carbon dioxide produced in hay might be used to indicate the loss of nutrients in the material. In 1930 hay with 33 per cent of moisture produced brown hay while hay with 32.5 per cent moisture produced good green hay. The hay with 33 per cent of moisture produced a much greater amount of carbon dioxide throughout the test. Hay might lose its color due to a rapid accumulation of carbon dioxide and a sudden rise in temperature and not have as much of the carbohydrate material consumed as hay of equally brown color which had gone through a protracted heating period.

The general belief that brown hay is as good as normal green hay for feeding purposes and that black hay is but slightly inferior needs some revision and some further investigation. The suggestion of Grasemann(21) that the inferior feeding value has been hidden in ordinary feeding of the hay due to the greater consumption of the brown hay seems justified by what little evidence there is available on the subject.

The salting of hay at the time of stacking or of placing in the mow is an old practice. Many farmers still make it a practice to salt their hay though it is not believed to be so common as formerly. Price (9) states that the old-time custom of salting hay in the mow has largely disappeared. He regarded this as unfortunate as salting has been an accepted means of guarding against combustion.

In the mowing studies the use of salt, varying from ½ to 2 per cent, has been tested in eight tests. Markedly beneficial results with the use of salt were obtained in one test and slightly beneficial results in a second, while no appreciable differences were noted in six others. In five of the six tests which showed no marked differences the heating of the hay was very slight in both the salted and the unsalted hay.

The most beneficial results were secured in 1928 in which two mows with 25.89 per cent of moisture were compared, one of which was salted at the rate of 2 per cent of salt and the other not salted. In the first five days there was very little difference in the temperatures but starting on the fifth day the differences were rather marked. The greatest difference occurred on the 8th day after mowing, at which time the salted hay was 21°C. cooler than that not salted. The salted hay was free from mold and green in color while that not salted was brown in color and had molded.

In the 1930 test, hay that was salted at the rate of 1 per cent did not heat quite so much, did not have quite so much carbon dioxide produced and was distinctly less moldy than hay of the same moisture content that was not salted. The hay in each mow was brown when the experiment was discontinued.

In one test in 1930 in which hay was packed in insulated containers, the hay with 1 per cent salt did not have quite so much carbon dioxide present as hay with the same moisture content but without the salt. The temperatures of the two were practically the same.

The influence of salt on the heating and on the quality of hay produced when baled from the field was tested. The hay was all field cured and did not heat excessively. No effect that could be credited to the presence of salt was observed in hay baled with 16.07, 19.2 or 23.55 per cent of moisture. In hay baled rather loosely with 30.3 per cent of moisture, two bales had 1 per cent salt sprinkled in as the hay went into the press box. The salted bales cured out a good green color and were graded as U. S. No. 1 by Prof. C. S. Dorchester. Of two bales not salted one was brown inside and graded as Sample Grade, while the other, which had been stored separately, was graded No. 2.

While this evidence on the value of salt in hay curing is inconclusive, the facts would certainly seem to warrant the further investigation of this problem and the recommendation to farmers that they use salt on hay not thoroughly cured.

Tests on the effect of baling hay with varying moisture content have been made in four series. For each of the four series the highest moisture content that the hay could have at the time of baling and still produce green hay after the heating period was 27 per cent, 26.3 per cent, 30.3 per cent and 22.7 per cent. In practically every test hay with less than 25 per cent of moisture cured out without damage to the color of the hay when stored in a dry place, with the bales properly spaced for air circulation. Thirty per cent moisture was the maximum moisture content at which the hay was baled without the loss of the green color.

It would appear that hay with less than 25 per cent moisture may be baled if precautions are taken to provide ventilation when in storage. The work on baling hay should be continued with some attention given to the method of storage after baling for best results. The influence of the density of the bale on the keeping qualities has not been tested. Apparently the temperatures developed in bales of hay correspond to those in the mow when the hay has the same moisture content.

SUMMARY.

A review of the literature on methods of curing hay shows that very little experimental work has been done on this subject. A review of the literature on storage of hay reveals a great many theories with but very little experimental evidence on practical storage problems.

The great difficulty in measuring the progress of the curing process has largely been overcome in these studies by the perfection of a weighing device which enables the operator to determine the moisture content of the hay while it is curing in the field.

In connection with the moisture content and the moisture loss from the plant in curing; the variation in the moisture content of the plant was shown to be a minor factor in determining the time of day to cut hay. The stomata were observed to close promptly when the plant was cut and to open slightly by the time the plant was ¼ cured. The leaf was found to be unimportant as a means of removing moisture from the curing stems.

Alfalfa hay was found to cure out more rapidly in the swath than in the windrow and more rapidly in the windrow than when cocked.

Hay that was $\frac{1}{4}$, $\frac{1}{2}$ and $\frac{3}{4}$ cured in the swath prior to windrowing cured out more rapidly than the hay windrowed at once, and the longer the hay was allowed to remain in the swath the sooner it was cured.

Cocking hay, either at once or after partial swath or windrow curing, delayed the curing process. Green hay in large cocks heats and loses its color. Good quality hay is made by cocking after partial swath or windrow curing.

Turning average sized windrows with the rake in good curing weather was found to be slightly detrimental as no appreciable time was gained and the quality of the hay was slightly lowered. Turning large windrows or windrows wet by rains caused them to cure out more rapidly and gave a better quality of hay.

Tedding hay was not found to be advantageous in any way in these experiments and was detrimental to the quality of the hay. The tedder may be valuable in extremely heavy swaths of hay.

Complete swath curing resulted in the greatest loss of leaves; $\frac{3}{4}$ and $\frac{1}{2}$ swath curing were next in amount of leaves lost. Windrowing at once, and $\frac{1}{4}$ swath curing followed by windrowing, resulted in the least loss of leaves. The leaf loss in swath curing hay was increased by the use of the tedder. The turning of the windrow with the rake caused an additional leaf loss in windrow cured hay.

The color of the hay produced was best in hay cocked after $\frac{1}{4}$ swath curing, followed in order by complete windrow curing, $\frac{1}{4}$ swath cured then windrowed, cocked after $\frac{1}{2}$ swath curing, $\frac{1}{2}$ swath cured then windrowed, cocked after $\frac{3}{4}$ swath curing, $\frac{3}{4}$ swath cured then windrowed, and last, hay swath cured completely.

The evidence and theories on heating of hay indicate that heating, from the temperature of the plant to the point of ignition, is due to chemical oxidation processes. These processes may be helped by respiration of the living cells in the plant up to 40-45°C. and by the work of microorganisms in producing unstable, unsaturated compounds from air temperature up to 70°C. Beyond this point the heating is due entirely to chemical processes.

The presence of living cells in the stems and leaves of field cured hay plants has been shown during the course of these studies.

During these experiments hay was placed in the mow with as low as 20 per cent and as high as 58.7 per cent of moisture. The degree of heating was not found to be directly proportional to the moisture content of the hay. Hay with below 30 per cent of moisture ordinarily may be considered safe from heating to a destructive or dangerous degree. Hay with less than 27 per cent of moisture may be expected to retain its green color. The hay generally heats somewhat immediately on being mowed, then cools; this is followed by a second heating period in which the highest temperature is reached in 8 to 10 days after mowing, after which the hay cools gradually.

The amount of carbon dioxide present in the mow is a fair indication of the degree of heating of the hay in the mow. The accumulation of carbon dioxide in the presence of moist, hot material results in a transformation of the chlorophyl accompanied by a change in color from green to brown.

The green color of hay was usually destroyed when the heating exceeded 50°C. Clean brown hay is formed at temperatures above 55°C. and below 70°C. Generally moldy, grayish-brown hay is formed when hay discolors between 40 and 50°C.

Clean brown hay is formed by heating quickly to 55°C., while if the heating is prolonged at 50° C., or less, and later heats to above 55^{o}C. the hay is dusty.

The value of salting hay in the mow was tested 8 times, with a distinctly beneficial effect once, slightly beneficial once, and apparently of no benefit in six trials.

When hay baled from the field with 23 per cent of moisture was carefully stored there was no detrimental heating.

CONCLUSIONS

The results secured in the studies by the author and reported here would seem to justify the following conclusions.

1. The moisture content of the plant in the field is not an important factor in determining the time of day to cut alfalfa for hay in Iowa.

2. Alfalfa hay dried out more rapidly when left spread out in the swath than when exposed in any other manner.

3. Alfalfa hay retains its leaves and color better when dried in the windrow or in the cock than when spread in the swath.

4. The best color of hay is obtained by curing in the cock after one fourth swath curing.

5. The use of the tedder ordinarily is detrimental to the quality of alfalfa hay.

6. Alfalfa can be cured best by windrowing the hay after one fourth swath curing.

7. There are living cells in the leaves and stems of field cured alfalfa hay.

8. Hay put in the mow with below 30 per cent of moisture may be considered safe from excessive heating.

9. Hay put in the mow with 25 per cent of moisture or less can be expected to retain its color and quality.

10. The green color of hay is destroyed in mows when there is an accumulation of water vapor and carbon dioxide at temperatures between 40 and 50°C.

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